CALIFORNIA AGRICULTURAL EXPERIMENT STATION

CATERPILLARS DESTRUCTIVE TO TOMATO

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Corn earworm, sometimes called tomato fruit worm, is the most important of the caterpillars which attack tomato in California. This pest is abundant and widely distributed throughout tomato-growing districts. It normally completes its larval growth inside the tomato fruit, making detection difficult.

THIS BULLETIN

is a research report on the value of the new insecticides—DDT, DDD, and others—as substitutes for calcium arsenate in the control of tomato pests.

After years of use as a dust, calcium arsenate has come into disfavor because of its drift into adjacent fields with resultant injury to susceptible plants, bees, and livestock.

Certain questions arose quite naturally from this situation:

- Could dusting equipment be improved to help control drift?
- Might calcium arsenate applied as a concentrated spray be as effective as the dust, and less apt to drift?
- Would the new insecticides give more or less satisfactory control of caterpillars than had been given by calcium arsenate?
- If used, what would be the after-effects of such compounds as DDT: to the soil, as residues on canning tomatoes, to forage crops and bee pastures?

These questions were the basis for the investigations conducted in 1946 and 1947 by the authors. The findings reported in this bulletin are the result of two years of extensive experimentation on small replicated plots and on commercial plantings.

EARLIER TOMATO investigations, begun in 1935, had already determined the life histories and habits of the insects as well as the best control measures based upon the insecticides available before the advent of the many new organic compounds. Descriptions and habits of the insect pests, previously reported in Agricultural Experiment Station Bulletin 644, are repeated and substantially expanded herein, inasmuch as Bulletin 644 is now out of print.

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CATERPILLARS DESTRUCTIVE TO TOMATO

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CALCIUM ARSENATE has long been one of the most important insecticides used to control caterpillars attacking tomato. It has been primarily used as a dust and although it has resulted in satisfactory control of most caterpillars, its drift to fields other than the ones being treated has given rise to complaints. Crops susceptible to arsenical burn have been injured, and forage crops and bee pastures have been contaminated. The seriousness of the problem has increased due to faulty application, to the application of the insecticide when not needed, and to an increase in recent years in the acreage devoted to tomato production.

In 1946 investigations were undertaken to determine means of eliminating the hazard associated with the application of calcium arsenate. The tests were continued in 1947. The problem was attacked from the standpoint of developing better methods of application, and by investigating promising new insecticides to find out whether some of them might not serve as satisfactory substitutes for calcium arsenate in the tomato insect control program. The results of these investigations are presented in this bulletin.

The investigation has been limited to the northern tomato-growing sections of the state and results and conclusions given are based upon these findings.

THE CATERPILLARS AND THE DAMAGE THEY DO

Knowledge of the pests, their habits, and the damage they inflict to tomato is the key to an effective control program.

Cutworms of several species are the most important of the caterpillars attacking tomato. The most destructive species is the corn earworm, *Heliothis armigera* (Hbn.), although the yellow-striped armyworm, *Prodenia praefica* Grote, and the beet armyworm, *Laphygma exigua* (Hbn.), do much damage, and under some conditions are more important than the corn earworm. The alfalfa looper, *Autographa californica* (Speyer), sometimes occurs in abundance but is of little importance because its feeding is confined almost entirely to the foliage. All of the above cutworms spend their entire larval life upon the plants, which distinguishes them from a second group which feed only at night, and during the day hide in the soil or the debris covering it. Occasionally caterpillars belonging to this group are troublesome.

The tomato pinworm, *Keiferia lycopersicella* (Busck), and the potato tuber moth, *Gnorimoschema operculella* (Zeller), are insects of similar habits, and in certain areas or under favorable conditions are likely to be very destructive to tomato.

The tomato hornworm, *Protoparce sexta* (Johan.), and the tobacco hornworm, *P. quinquemaculata* (Haw.), are important pests and are particularly destructive in the warmer interior valleys.

All the above pests pass through four distinct stages of development: egg, larva (caterpillar), pupa (chrysalis) and adult (moth). Damage is only inflicted during the larval stage.

Any discussion of pests of tomato must include, in addition to the caterpillars, mention of the tomato mite. Where not controlled, this pests causes serious dam-

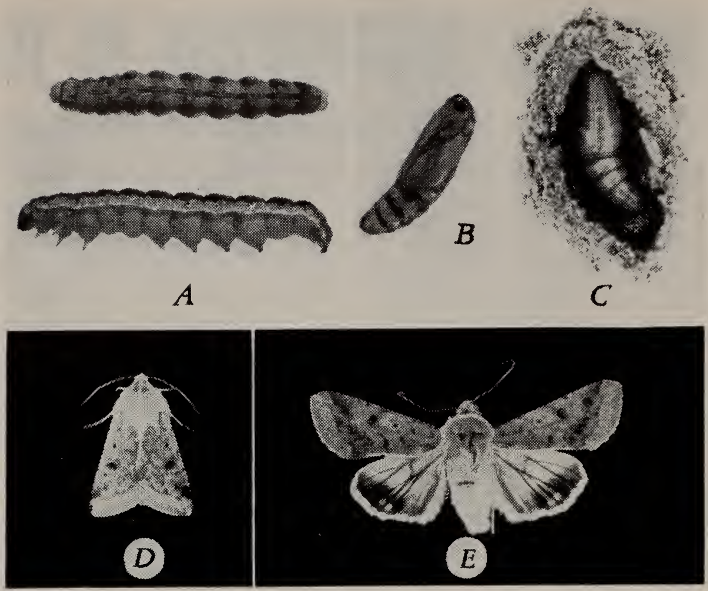


Fig. 1. Stages in the life cycle of the corn earworm: *A*, mature larvae; *B*, pupa removed from earthen cell; *C*, pupa within earthen cell; *D*, adult in a position of rest; *E*, adult with wings spread. (All natural size.)

age through defoliation. Therefore, although this bulletin is intended to treat primarily with caterpillar control, there is included on page 18 a description of the mite and its destructiveness. Control of the mites can be accomplished in conjunction with the control of caterpillars. Suggestions for such control are given as part of the integrated program discussed on pages 22 and 33.

Corn Earworm

Corn earworm is one of the most serious and most prevalent of the caterpillars attacking tomato. When found on tomato this insect is frequently referred to as the tomato fruit worm.

The stages in the life history of the corn earworm with the exception of the egg stage are shown in figure 1. The length of time spent in any one stage is influenced by the type of food and weather conditions. In the northern tomato-growing regions of California, there are at least three complete generations a year. The winter is passed in the pupal stage in earthen cells 2 to 10 inches beneath the soil surface. Emergence of the moths from the overwintering pupae occurs principally during the months of May and June.

The adults (fig. 1, *D* and *E*) have a wing expanse of about 1½ inches, and their basic color is tan to brownish tan, over which a rather inconspicuous but definite darker pattern is superimposed. Egg laying begins several days after emergence and continues until death; a single female may lay 500 to 3,000 eggs throughout the fields. Quaintance and Brues (1905)[1] reported a single female depositing 780 eggs in one day. Usually at dusk on warm days in heavily infested tomato fields, female moths may be seen flitting here and there, seldom flying higher than the tops of the plants, and laying eggs at random over the vines. Only an instant is required for the deposition of an egg. Although egg laying usually begins just before dusk, on occasions

[1] See "Literature Cited" for citations, referred to in the text by author and date.

moths may be observed laying eggs earlier in the day, especially if the day is overcast.

The eggs are dome-shaped and longitudinally ridged. At first the color is waxy white, but as the incubation period advances they become darker in color due to the development of the larva. During warm weather they hatch in from 3 to 5 days.

In growing the larvae cast their skins about five times, and under favorable conditions reach maturity in approximately 2 to 3 weeks. When full-grown (fig. 1, *A*), they measure about 1½ inches in length and exhibit a marked variation in color from green to almost black, and may be marked with longitudinal stripes of various colors. In the later stages they are very cannibalistic and, where two meet in competition or combat, the larger one is usually victorious.

On completing development, they burrow into the soil and construct pupal cells a few inches below the surface, from which they build tunnels upward to within a half inch of the surface for the subsequent emergence of the adults. Larvae of the overwintering individuals generally pupate deeper in the soil than those of the summer brood. The pupae (fig. 1, *B* and *C*) vary from dark amber to chestnut brown and are about ¾ of an inch in length. The duration of the pupal period is only 2 to 3 weeks during the summer; those formed in the fall remain as pupae all winter or longer.

Corn earworm prefers other crops

The corn earworm has a very extensive host range and feeds on many different species of wild and cultivated plants. It is an important pest of corn, cotton, tomatoes, tobacco, beans, and several other crops. Sweet corn is the preferred host, although in northern California caterpillars are present in large numbers on beans and other legumes. Tomatoes are not a preferred host, but are subject to serious damage because they mature later in the season than most crops and are therefore in an attractive state of growth at a time when other crops are reaching maturity and drying up. Host plants that are developing their fruiting bodies and making a rapid growth are most attractive to egg-laying moths.

Although tomato plants are set out in the field early in the season, they are seldom subjected to serious attack until the latter part of July or later, and there are areas in central and northern California where they may go through the entire season without being seriously infested. The reason for this in part appears to be linked with host sequence or types of crops grown in the various sections. The overwintering moths start emerging as

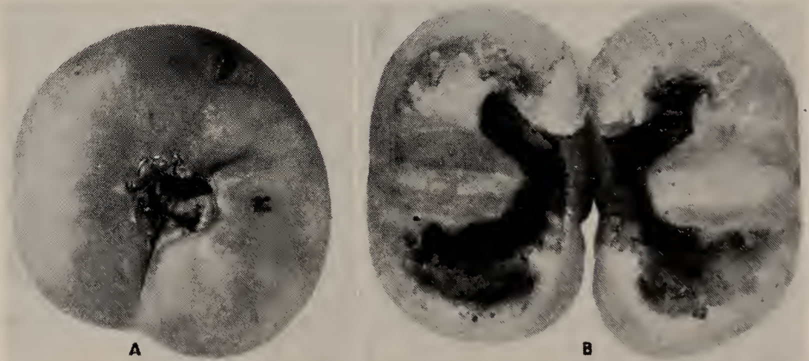


Fig. 2. Corn earworm damage to tomatoes; *A*, advanced injury of the stem end with caterpillar in burrow; *B*, tomato cut in half to show the internal destruction caused by the caterpillar.

Sample Tomatoes Show Infestation

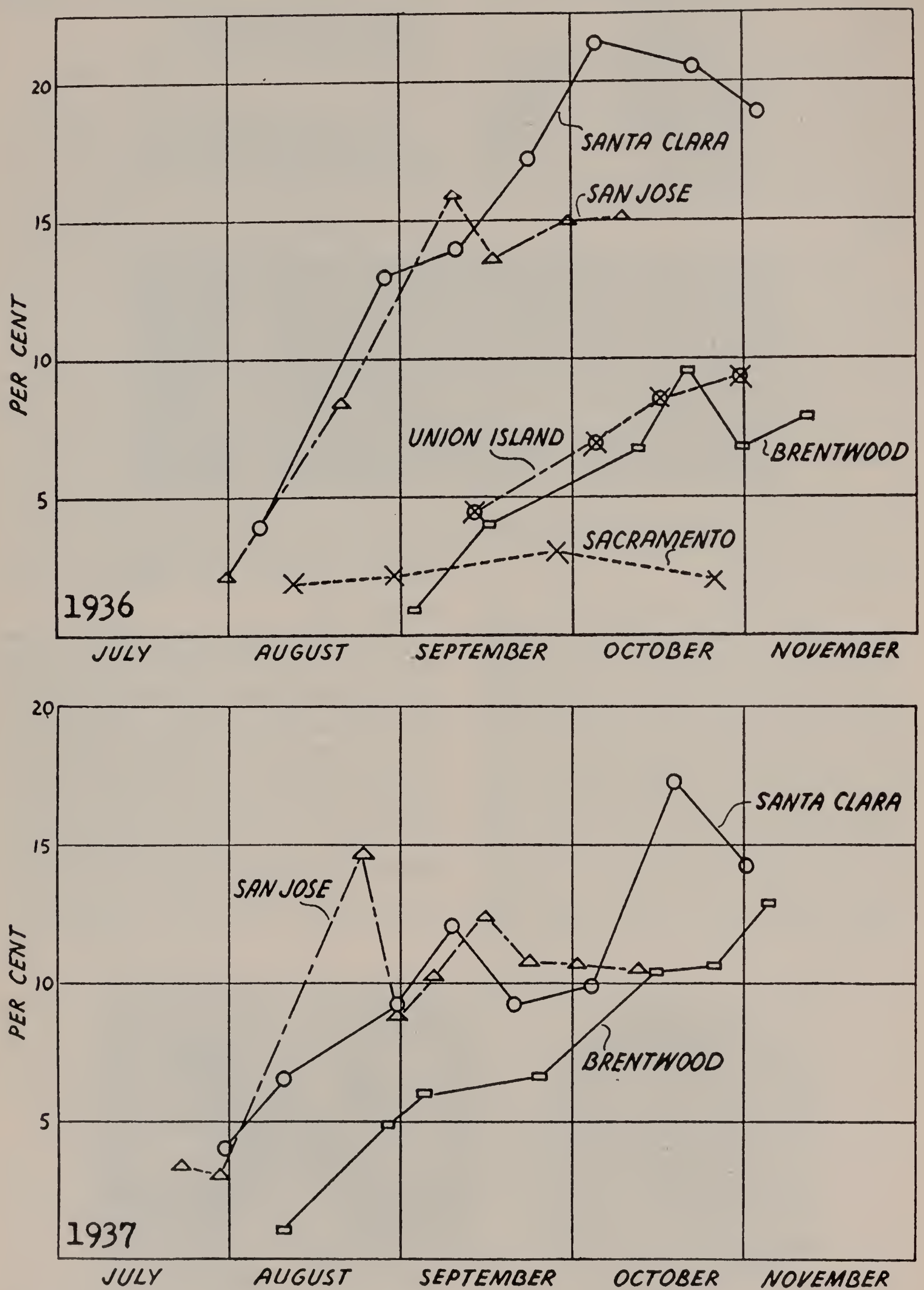


Fig. 3. Infestation trends of the corn earworm are shown in the charts above from samples taken in 1936 and 1937 in several northern tomato-growing locations. It will be seen that serious infestations of this pest do not occur before the first of August. The charts are in terms of the per cent of infested tomatoes found in the samples taken.

early as May, and by the end of June sweet corn may be severely infested. By July nearly all ears of sweet corn may be attacked, while tomatoes growing only a short distance away may show a very low infestation. Beans also appear to attract egg-laying moths to a greater extent than tomato and in some sections there is a considerable increase in the population on this crop. The moth populations that arise from the preferred hosts then migrate to tomato when these earlier crops are no longer available. Similar observations have been made by other investigators. Isely (1935) reported that a combination of corn and leguminous crops may lead to a serious outbreak on cotton. If an infestation once becomes established in a locality, it is likely to continue for the remainder of the season. If established in August, there is apparently sufficient time for two broods of larvae to appear in the field before tomato harvest is completed.

Infestation may be high

Where an infestation is severe, more than 50 per cent of the tomatoes may be destroyed or rendered unfit for human consumption. The moths lay their eggs singly and at random over the periphery of the vine. The newly hatched larvae start feeding on the foliage. If a fruit is not encountered, they may complete their development on the foliage, in which case they are green in color and the tubercles from which the hairs arise do not appear to be as conspicuous as those present on larvae that develop within the fruit. The larvae apparently experience little difficulty in finding the fruit as is evidenced by the fact that many of them enter the fruit at a very early stage of development. Entry is usually made at the calyx or stem end, and some of the larvae are so small that one must look very carefully to detect the point of penetration.

Development may be completed within a single fruit, although a larva may damage or destroy more than one tomato. A nearly mature caterpillar often leaves the fruit in which it has developed and feeds externally on other fruits in the same cluster. Sometimes it even drops to the ground and feeds externally on a fruit that is resting on the soil surface. This and other types of external feeding are usually characterized by irregular feeding holes. Typical advanced calyx-end injury is shown in figure 2.

Examine small fruit

There is a strong tendency for the small corn earworm larvae to enter developing tomatoes 3/4 to 2 inches in diameter. The beginning of an infestation can therefore be determined by picking and thoroughly examining fruit in this size range. As far as the corn earworm is concerned, a control program need not be started until 2 to 3 per cent of the fruit in this stage of development shows signs of infestation. Usually no less than 300 fruits should be picked at random throughout the field in determining the degree of infestation. Late in the harvest season small larvae may enter the ripe tomatoes as well as the small developing green fruit. Where this occurs the canner is caused much annoyance because these infested fruits are nearly impossible to detect on the sorting belts.

Begin in August

Serious infestations by the corn earworm do not usually make their appearance before the first of August. This is well illustrated in figure 3 where charts show the trend of the infestation for several regions, based on the amount of infested fruit observed in the check plots associated with experiments conducted in 1936 and 1937. The reason for designating the corn earworm as the most important caterpillar attacking tomato is due to its abundance, wide distribution, and to the fact that it normally completes its larval development within the tomato fruit. The degree of injury varies greatly from year to year, and from field to field in any given year.

Confusion with Heliothis phloxiphaga

Heliothis phloxiphaga (Grote and Robinson) is likely to be confused with the corn earworm, to which it is closely related. Early in the growing season, moths of the former insect (fig. 4) may be present in large numbers in tomato fields. The females lay their eggs, which are similar to those of the corn earworm, at random over the tomato vines in the same manner as does the corn earworm. However, this fact need cause no concern, because the larva of this insect is unable to develop on either the foliage or the fruit of the tomato. The larvae feed on cultivated crops such as lettuce and alfalfa. There are a number of native hosts and in late summer and early fall they may be found breeding in large numbers on tarweed and gum plant.

Yellow-Striped Armyworm

The adult of the yellow-striped armyworm (fig. 5) has a wing expanse of about $1\frac{1}{2}$ inches. It is grayish in color. The forewings have an intricate color pattern of slate and buff markings, while the hind wings are silver and gray.

Eggs laid in masses

Eggs are laid in masses upon the plants, which results in a concentrated attack by the larvae, although as they develop the larvae tend to disperse. The larvae are rather colorful, being almost black in color with two prominent and many fine, bright yellow stripes on the side. When full-grown they may attain a length of slightly more than 2 inches. Mature larvae leave their host plants, burrow into the soil, and construct earthen pupal cells, one to several inches below the surface. Here they transform into adults and after several weeks the moths emerge. There are several generations a year and the winter is spent in the pupal stage. Moths emerge from the overwintering pupae in late April or May, mate, and lay eggs on host plants available at that time.

Fig. 4. Adult moths of *Heliothis phloxiphaga* (G. and R.). This pest is frequently confused with corn earworm because of resemblance, however this one damages neither foliage nor fruit of tomato.

May migrate from other fields

The yellow-striped armyworm attacks many kinds of cultivated and native plants. Among the important crops are alfalfa, beans, cotton, tomato, and melons. The pest, although present, does not cause serious damage every year. On occasions it is very destructive and causes widespread damage. It probably occurs in greatest numbers on alfalfa, and under severe conditions this crop may be defoliated. Infestations on other crops arise either from eggs deposited in the field or from migrations of caterpillars that occur when nearby infested alfalfa fields are cut. Migrating larvae may cause severe damage to the outer rows of plants in adjacent fields. The depth of penetration is usually not great, but in the case of tomatoes many caterpillars, by following the furrows, may wander rather far into the field if the rows run in the same direction as the migration. During 1947 an outbreak of considerable proportions occurred and had it not been for control measures directed against the pest, the tomato crop in many fields would have been destroyed or very seriously injured.

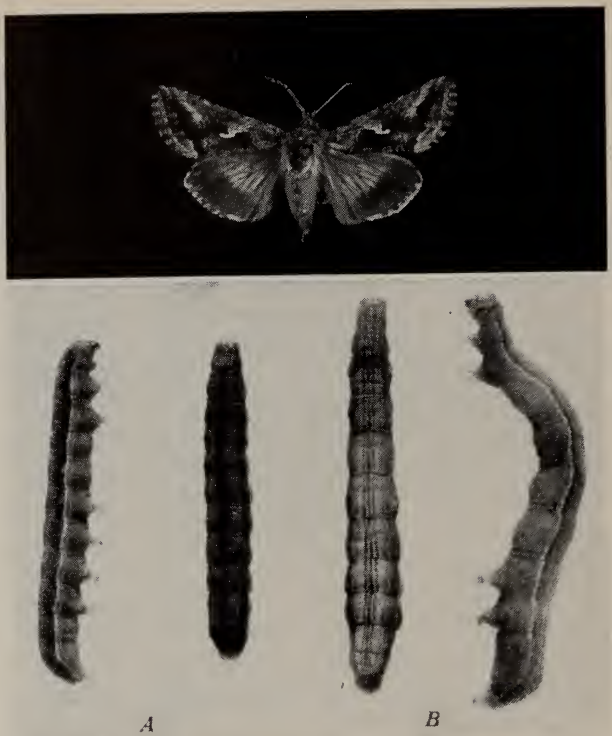
The yellow-striped armyworm feeds both on the foliage and the fruit of tomato. Unlike the corn earworm, it does not enter the fruit, but eats small to large irregular holes in its surface. Its most serious attacks on tomato occur from July through the middle of September.

Night-Feeding Cutworms

There are several species of cutworms which attack tomato only at night. Under some conditions they are likely to be rather destructive. The adults of these caterpillars are somber in color and are active only after dark. The caterpillars exhibit a dull color pattern and are usually dark brown or grayish. When mature, the caterpillars burrow into the soil to pupate. All feeding is done at night, the caterpillars hiding in the soil or surface debris during the day. These pests injure

Fig. 5. The yellow-striped armyworm, *Prodenia praefica* Grote. Above, as a moth this species is grayish in color; the forewings have an intricate pattern of slate and buff markings while the hind wings are silver and gray. Below, typical injury to tomato by the caterpillar.

Fig. 6. Above, adult of alfalfa looper, frequently seen flying over the tomato fields; below, *A*, full-grown larvae of the beet armyworm, *Laphygma exigua* (Hbn.); *B*, full-grown larvae of the alfalfa looper, *Autographa californica* (Speyer).



tomatoes by eating irregular holes in the surface, and those tomatoes which rest on the ground are in general the most seriously injured.

Early in the season this group of cutworms sometimes causes serious damage by cutting off recently transplanted tomato plants.

Beet Armyworm

The adults of the beet armyworm are a mottled gray with distinct paler markings on the forewings, and have a wing expanse of about one inch. The eggs are laid in groups over the host plants. The larvae (fig. 6, *A*) when mature measure a little more than an inch in length and appear in several color phases which range from pale green to nearly black. In all cases, however, the basic pattern is the same. They are darker above than below and down each side there is a lighter stripe. Also, on the dorsal side a close examination will reveal a number of closely set very fine longitudinal lines. There are several broods each year and in the winter they remain in pupal stage.

The beet armyworm feeds upon a wide variety of native and cultivated plants. It is one of the most common and widespread pests to be found in California. It feeds on most truck, field, and forage crops, and sometimes occurs in sufficient numbers to do serious damage. It is present in tomato fields every year, and at times in certain fields it may be the most important caterpillar attacking tomato. It is primarily a foliage feeder, but it will also seriously attack the fruit. It will occasionally enter the fruit but like the yellow-striped armyworm it usually feeds externally, eating single or closely grouped circular or irregular holes in the fruit. In many cases the feeding is of a very superficial nature, and little loss would be occasioned if it were not for rot and decaying organisms entering the wounds.

The pest occurs in tomato fields from early summer to the end of harvest. It is usually most abundant from late July until early November. Although found in

most fields it is probably most common and destructive in the warmer interior valleys. Under severe conditions of infestation it is not uncommon to find 25 to 50 or even more caterpillars on a single tomato plant.

Alfalfa Looper

The larvae of this insect are very common in tomato fields. The caterpillars (fig. 6, *B*) are pale green and longitudinally striped with fine whitish lines. They are easily distinguished from other caterpillars found on tomato by the fact that in crawling they arch their backs. This characteristic has given rise to the common name "looper." Pupation does not occur in the soil, but towards the crown of the plants or in the debris covering the soil under the plants. They spin a light silken cocoon, and in so doing may fold a leaf or tie together some of the debris. It is not uncommon to find these cocoons in tomato fields, and the amber or chestnut-brown pupae are revealed when the cocoons are torn open.

This insect is a foliage feeder and only on very rare occasions will it feed on a fruit. Although it may be found in fair abundance, no situation has been encountered where enough damage was being done to justify control measures.

Tomato Pinworm

The adults are small gray moths about ¼ inch from head to tips of folded wings. The eggs are very small. When first laid, the eggs are whitish but become darker as the incubation progresses. When newly hatched, the tiny larvae are light pinkish in color. When full-grown they are ¼ inch in length and to the naked eye appear grayish purple. This color serves to distinguish them from the larger, lighter-colored larvae of the potato tuber moth. A mature larva is shown in figure 7, together with a mature larva of the potato tuber moth to show the relative difference in size.

In California the most complete study of this insect has been conducted by Elmore and Howland (1943) and much of the following has been summarized from their report. The larva of this insect is a leaf miner and a leaf folder but will also frequently bore into the fruit during the latter half of its larval existence. Under favorable temperature conditions development is very rapid, and under some California conditions there may be as many as seven or eight generations in a year. The winter is passed in the pupal stage at or near the soil surface. The pest is active from early spring and until frosts kill its host plants in the fall.

Size makes detection difficult

The preferred hosts of the tomato pinworm are tomato and potato. It has also been reported on eggplant, horse nettle, and blue witch nightshade.

In California the insect occurs throughout the southern portion of the state, most of the San Joaquin Valley, and in very limited numbers in Alameda, Santa Clara, and San Benito counties. In the San Joaquin Valley it has never been taken by the writers north of the Tracy area, and seldom has it been found to be destructive in tomato fields north of Merced County. Most of the northern producing

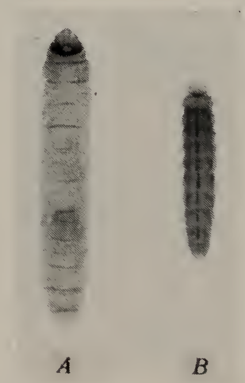


Fig. 7. *A*, Full-grown larva of the potato tuber moth, *Gnorimoschema operculella* (Zeller); *B*, full-grown larva of the tomato pinworm, *Keiferia lycopersicella* (Busck). (x3.)

section of the state is entirely free of the pest, or at most, subject only to light infestation in certain fields in the southern portion.

Where abundant the tomato pinworm may cause serious damage to the foliage, and nearly 100 per cent of the fruit may be infested. The larvae commonly attack the fruit at the stem or calyx end (fig. 8) although they may enter the fruit at any point. The larvae that enter beneath the calyx generally confine their feeding to the core, while those that enter at other points usually feed on the fleshy portion of the tomato just beneath the skin. This latter type of injury is similar to that of the potato tuber moth larva shown in figure 10, *B*. One characteristic feature concerning injury by both of these insects is that their burrows are dry, and this is the case whether they enter at the calyx or through the side of the tomato. Because of their small size they do not penetrate very far into the core, and coring of the fruit usually removes the pinworms beneath the calyx. More than one larva may attack a single fruit. After infested fruits are picked, the larvae quickly spin webs over the entrances to their burrows, which sometimes make their presence and injury difficult to detect.

Because the pinworm passes through a number of generations in a season, it generally becomes more serious as the season advances. Greatest damage is likely to occur where tomatoes are produced from early in the growing season to late in the fall. Late summer- and fall-grown tomatoes in the central and southern San Joaquin Valley are very likely to be seriously infested.

Potato Tuber Moth

The potato tuber moth has a life cycle very similar to that of the tomato pinworm. It passes through a number of generations each year, and in storage, if food is present and the temperature does not fall too low, breeding continues throughout the year. The length of a single generation varies from about one month in the summer to three or more months in the winter. In areas where it is able to survive the winter, it probably passes through periods of low temperatures as a full-grown larva or pupa.

The adults are small and gray with silvery bodies and minute dark specks on

Fig. 8. Tomatoes seriously infested with the tomato pinworm, showing the several types of injury.

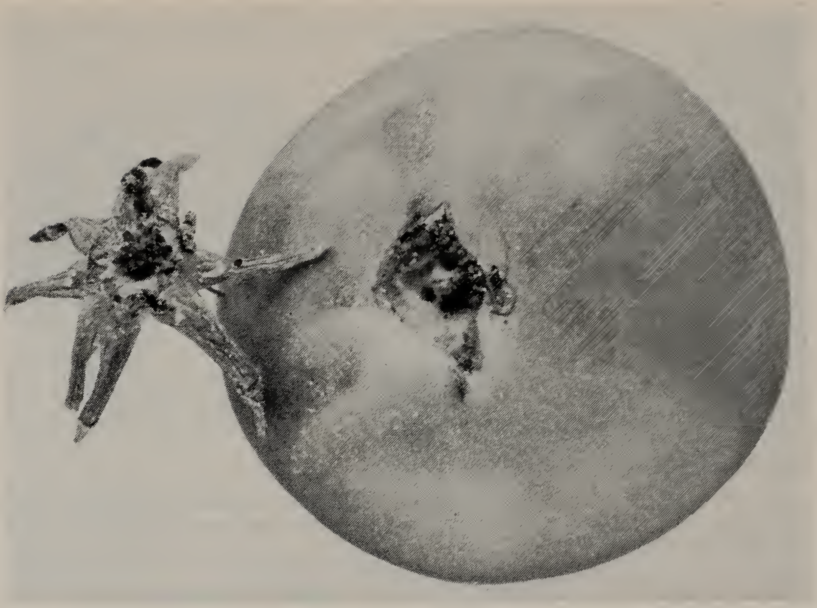


Fig. 9. Injury of the potato tuber moth on tomato. Calyx removed to show entrance to burrows.

the forewings. They are nocturnal and each female may lay from 150 to 200 eggs, which are small, oval, pearly white, and are deposited indiscriminately over the plant. The larvae (fig. 7, *A*) molt four times. When full-grown they are slightly more than 3/8 inch in length, and are either white, yellow, pinkish, or greenish, with the head and prothoracic shield dark brown. Pupation occurs in a white silken cocoon in any secluded place, on the host, in the surface soil, sacks, or storage bins. In tomato fields, most larvae probably pupate just beneath or on the surface of the soil.

Potato culture increases this pest

The hosts of the potato tuber moth are apparently limited to solanaceous plants, including potato, tomato, tobacco, Jimson weed, pepper, horse nettle, eggplant, and nightshade.

Tomatoes are subject to attack by the larvae of the potato tuber moth over a large portion of the tomato-growing area of California. In some areas such as Sacramento, Yolo, and Solano counties, it has never been a pest, and only on rare occasions are any individuals found. It appears to be most prevalent in the coastal regions, although serious outbreaks in localized areas have occurred in the San Joaquin Valley. Although the tuber moth larva feeds on other parts of the plant, damage is serious only on the fruit.

Infestations as high as 57 per cent have been encountered, although in most fields where it does occur usually less than 5 per cent of the tomatoes are infested. The potato tuber moth population normally increases as the season advances and generally is not a problem until late in the season. Early in the season very few infested tomatoes are encountered, but from late September to the end of the growing season, at least a few infested fruits will be found in most of the tomato fields in the coastal area.

Serious infestations are almost always associated with potato culture. Where tomatoes follow potatoes and where there are volunteer potato plants, there is always the danger of a serious infestation developing. Wherever destructive popu-

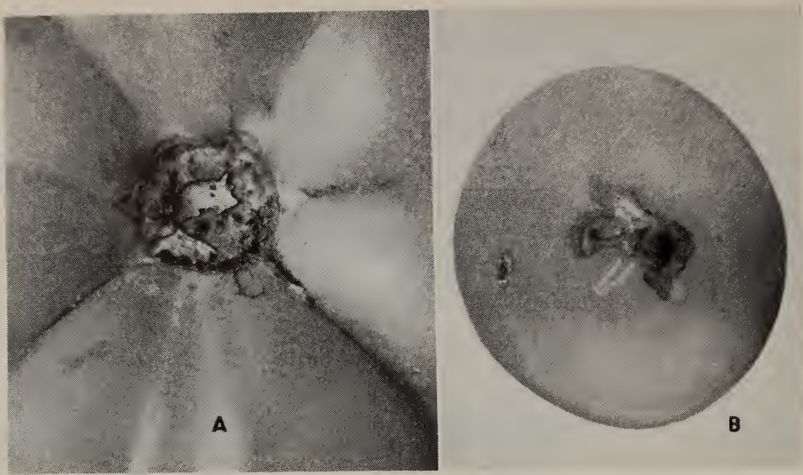


Fig. 10. Work of the potato tuber moth larvae on tomatoes: *A*, enlarged view of the calyx end showing the webbing over the burrow entrances; *B*, larval mines just below the skin.

lations have occurred in the San Joaquin Valley the above-mentioned conditions have usually prevailed.

Make webbed burrows

Because the injured fruit is rather difficult to detect, infestations, even though low, are of considerable annoyance. The larvae prefer to enter the fruit at the calyx end, and seem to be more numerous in those varieties of tomatoes which have firm, solid flesh. When entry is made at the calyx end, the burrows follow the core and the fleshy portions that radiate from it. In the early stages the burrows do not extend far into the fruit, but as the larvae increase in size, they may penetrate deep into the interior. When the calyx is removed, the entrances to the burrows are usually exposed (fig. 9). After the fruit has been picked for some little time, the larvae, if still present, close the entrance to the burrows with a webbing and the calyx end of the fruit appears as shown in figure 10, *A*. As this webbing tends to obscure the injury, the fruit must be carefully observed or the damage will pass unnoticed.

The potato tuber moth larvae will attack the fruit at any point. Where entrance is made at some spot other than the calyx, the larvae may act as miners and work just below the epidermis as illustrated in figure 10, *B*. They may penetrate deeper into the fruit if they encounter a fleshy part that radiates from the core.

A large number of larvae may enter a single fruit, although from one to three are the numbers most commonly found. Their mode of working and the type of damage done is very similar to that caused by the tomato pinworm. However, because of their larger size, the injury may be slightly more noticeable.

A survey made in 1944 in the Bakersfield area, where many potatoes are grown, well illustrates the above. Six tomato fields were examined. In some of these there were volunteer potato plants, and despite extensive control measures, rather heavy infestations of the potato tuber moth were found.

The average infestation of tomatoes by potato tuber moth larvae, per 100 fruits, ranged from 2 to 25 per cent. The fields had been dusted three to four times with insecticides containing cryolite or arsenate of lead. Had there been no control, it is likely the infestation by potato tuber moth larvae in some of these fields would have exceeded 50 per cent.

Tomato and Tobacco Hornworms

The tomato and tobacco hornworms are very similar in all stages. The adults are large moths with a wing spread of 4 to 5 inches and are commonly called "sphinx" or "humming bird moths." They are swift fliers and are crepuscular and nocturnal in habit. They are frequently seen at dusk hovering over flowers in a manner similar to humming birds, hence one of their common names.

The adult of the tomato hornworm is shown in figure 12. It has six orange-colored spots on each side of the abdomen which distinguishes it from the tobacco hornworm which has but five. They lay their large, round, greenish eggs at random on the undersides of the leaves of their host plants. The larvae, which are called "hornworms" after the characteristic horn on the tip of the abdomen, often attain a length of 4 inches. A mature tomato hornworm larva is illustrated in figure 11. It is green in color, has 7 diagonal white stripes on its sides and a red horn.

The tobacco hornworm looks much like the tomato hornworm, but can be distinguished from the former in that along the sides eight "_\" markings replace the white diagonal lines and in the larger specimens the horn is black instead of red. The tobacco hornworm also has a melanistic color phase. When mature, the larvae burrow into the soil and pupate. The pupae which are chestnut brown in color are shown in figure 12. They can be distinguished from one another by the sheathed proboscis which is longer in the tobacco hornworm. The winter is passed in the pupal stage. The moths emerge during April–May, and there are probably no less than three generations in a season.

Cause serious defoliation

The host range of the tomato hornworm and tobacco hornworm is rather extensive. Both native and cultivated crops are attacked. Important among the latter are tomato, tobacco, and potato. Of the native hosts Jimson weed is probably by far the most important. The larvae strip the leaves from tomato vines as shown in figure 13. When they are abundant serious damage may also be done to the developing fruit (fig. 14). Although they may occur in any tomato-growing area, they are most serious in the warmer interior valleys, and if severe infestations are allowed to go unchecked, an entire field may be defoliated.

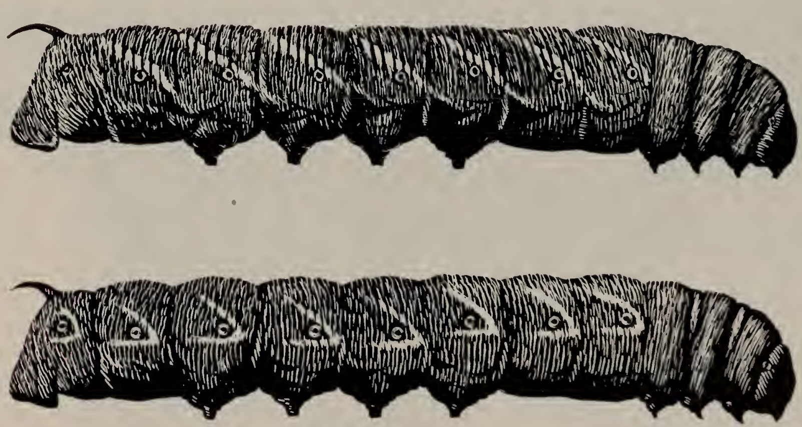
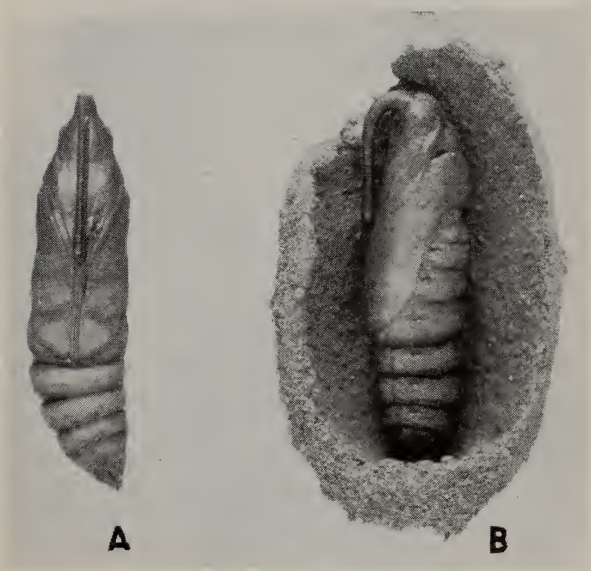


Fig. 11. These drawings show clearly the similarity of the two hornworms which attack tomato. Above, tomato hornworm, *Protoparce sexta,* and below, tobacco hornworm, *P. quinquemaculata.*



Hornworms at Three Stages of Life

Fig. 12. The caterpillar of the tomato hornworm, above, has hatched from the egg and has grown to full size. At left, *B*, is the pupa of the caterpillar, in its cell. The pupa of the tobacco hornworm is shown in *A*, at left, where its longer sheathed proboscis may be seen. Below, the adult moth of the tomato hornworm has emerged from its pupa.

Typical Hornworm Damage

Fig. 13. Tomato stems pictured above have been seriously defoliated by hornworms.

Fig. 14. Tomato fruits show injury by caterpillars of the tomato hornworm.

Fig. 15. The tomato mite, *Phyllocoptes destructor,* showing adults, immature, and eggs. (x40.)

Tomato Mite Another Pest Needing Control

The tomato mite, *Phyllocoptes destructor* Keifer (fig. 15), also known as the tomato russet mite, is a free-living, microscopic eriophyid mite, which appears slightly humped and tannish white under high magnification. It crawls about slowly on the surface of the leaves, stems, and fruit of the tomato plant and sucks out the cell contents. The stems and leaves sometimes, but not always, become greasy bronze or russet in color, but later they die. The infestation usually starts near the ground and as it progresses up the plant the lower leaves dry which gives the plants an open and unhealthy appearance. Mite damage should be suspected if the leaves on the basal portion of a plant are dead, and particularly if there is a zone where the leaves and stems show a greasy bronze discoloration, while the outer growth of the plant still appears normal.

The tomato mite reproduces from eggs and passes through many generations in a season. In the field, continuous reproduction has been reported by Bailey and Keifer (1943) from early May until frost.

Defoliates vines

The tomato mite feeds and reproduces on a number of solanaceous plants. Among the more favorable cultivated hosts are tomato, potato, and petunia. Uncultivated hosts which are less favored than the above include nightshades and Jimson weed (Bailey and Keifer, 1943).

Where not controlled, the tomato mite causes serious damage in California. It was not known to occur in this state until 1940, when it was found injuring tomatoes in a greenhouse at Modesto. Since then it has spread throughout the major tomato-producing regions. In the northern tomato-producing section, injury may appear during the month of June, but seldom becomes serious enough to be noted until late July and August. Damage in the southern San Joaquin Valley may occur at an earlier date and Michelbacher (1944) reported serious mite injury to a small planting of tomatoes near Edison, Kern County, on the first of June, 1944.

If not controlled, the tomato mite causes serious defoliation, which is particularly rapid during periods of hot weather, resulting in sunburned fruit and the loss of the crop. If damage by the tomato mite does not become apparent until after the first of September, there is little likelihood of its becoming destructive, and control measures rarely are justified after that date.

EXPERIMENTAL METHODS

Investigations were made on small plots and on commercial plantings, testing various equipment and new insecticides.

Plot Arrangement

Two types of plot arrangement were used in the investigation. In one, materials and methods of application were tested on small plots that were 10 rows wide and from 50 to 60 feet in length. Applications were made by hand equipment and the treatments replicated four times in a randomized experiment. In the other, treatments and methods of application were investigated on a commercial experimental scale. The treatments were applied with power equipment, were not replicated in a given field, and the plots ranged from 5 to 8 acres in extent, except for a single experimental series in 1946. In this, the individual plots averaged 0.85 of an acre, applications were made with power equipment, and each treatment replicated four times in a randomized experiment.

Equipment

In the case of the small plot replicated experiments, Root rotary hand dust guns (Model C-3) were used for the application of dusts and Hudson hand sprayers (Dumore No. 247) for the application of concentrated sprays. Power dusters and sprayers were used for the application of insecticides to the commercial blocks. Most of the ground dusting was done with a 5-row standard tomato duster equipped with three nozzles to the row, and arranged so that the dust was directed to the sides and the top of the plants. (The theory and operation of spraying machines: high pressure, compressed air, and mist sprayers, were presented by O. C. French in 1942.)

The ground machine used for applying concentrated sprays in 1946 was a compressed-air atomizing type (fig. 16). It was designed to supply compressed air at about 15 pounds per square inch and 7 cubic feet per minute to each nozzle, mixing with and atomizing the liquid at the nozzle. The spray material was carried in

Fig. 16. Three-row, compressed-air power sprayer in operation.

Fig. 17. A two-row commercially built vapor sprayer and duster used during the 1947 season.

a 75-gallon tank provided with mechanical agitation. The mixture was drawn from the tank by a small gear pump and forced to the nozzles at about 5 to 10 pounds per square inch and discharged at a rate controlled to give about 0.16 gallons per minute from each nozzle when spraying at the rate of 10 gallons per acre. The machine covered three rows at a time with three nozzles to a row; one on each side and one on top. The machine was of a design to give satisfactory coverage. It produced a spray with droplet size large enough to eliminate serious drift but not so large as to impair distribution or burn plants with materials of potential danger when unevenly applied.

Vapor spray machine used

The machine used in 1947 for ground spraying was a commercially built vapor spray type, known as a Naconizer (fig. 17) and variously called a vapor or mist sprayer, or duster. It could be converted to a straight duster by making a few mechanical changes. Both this machine and the one used in 1946 were designed to reduce the amount of liquid carrier required, by replacing a portion of the carrier of the suspended toxic ingredient with air. The obvious benefit of these machines is that the amount of liquid carrier required is greatly reduced. It is believed that the machine used in 1947 was superior to the one used in 1946 in that it gave better coverage to all parts of the vine due to deeper foliage penetration of the spray-laden air.

Improved equipment

The machine used in 1947 was equipped with a 15-gallon tank, and the spray mixture was agitated hydraulically with bypassed flow from the pump. The small centrifugal pump handled 20–30 gallons per minute at 7–10 pounds per square inch. When spraying at the rate of 10 gallons per acre, each nozzle discharged about 0.25 gallons per minute. A blower coupled directly to the driving motor furnished the high-volume air which picked up and atomized the liquid as it was discharged from a special nozzle. Air volume at each nozzle was about 500 cubic feet per minute at a velocity of approximately 150 miles per hour.

The capacity of the machine was two rows at a time. There were two nozzles per row and they were adjusted to the height of about 18 inches above the plants and directed into the sides of the row at an angle of 35 degrees. The nozzles were tilted backward at about 10 degrees to reduce laying the plants forward by the force of the high-volume air and the forward motion of the machine. Unless this condition was corrected, the plants were thoroughly sprayed only on one side. This equipment gave satisfactory mechanical performance with a minimum of breakdown. It was designed to be tractor-mounted and power-take-off-driven requiring about 15 hp. Because of its light weight and compactness, it was easy to handle.

Airplanes test dusts and sprays

Regularly equipped airplane dusters with gravity-flow hoppers were used for the application of dusts by air. O. C. French reported on the airplane dusters and sprayers in 1947.

The airplane used for spraying in 1946 produced droplets too large to give most satisfactory results. Not only was the atomizing device inadequate, but the plane also lacked precision shutoff valves at the nozzles which made it impossible to confine the spray to the field being treated. These difficulties, although still present, were largely overcome in the airplanes used in the 1947 investigations. Stearman biplanes equipped with wing-length boom applicators were used. One plane had the cluster nozzle system where several nozzles are controlled by one valve, while a second had a single nozzle per valve. The spray tank capacity of the planes was approximately 120 gallons. Both used hydraulic agitation obtained by forcing the excess of by-pass flow of liquid from the pump back into the storage tank. One of the machines used a power-take-off-driven pump mounted inside the fuselage and operating with pressure up to 90 pounds per square inch while the second was mounted in the main slipstream driven by a small propeller and operated on a relatively low pressure of 25 pounds per square inch.

Sampling Methods

Trends of infestation in the experimental fields were determined by following the infestation in the developing green fruit as well as that occurring in the ripe fruit. In making surveys the fruits were picked and carefully examined. During the harvest season the degree of infestation was determined for each picking that occurred in the experimental fields. From 200 to 600 fruits were examined, depending upon the size of the plots. For the small plot replicated experiments usually 200 fruits were examined per plot, while in the large commercial blocks 400 or more fruits were inspected. Infested fruit was divided into two categories, superficial and severe. The superficial category comprised those fruits which showed only a slight amount of injury, while the severe included those fruits that had been severely injured or were infested with a caterpillar.

Materials Used in Tests

A brief description of the primary materials used in the tomato investigations may be listed as follows:

Calcium Arsenate

This was a commercial grade preparation which contained 70 per cent of calcium arsenate. Reference to the use of calcium arsenate either in dusts or concentrated sprays in the text and tables applies to this grade.

DDT

Dichlorodiphenyl-trichloroethane was used as 3 and 5 per cent commercially prepared dusts. Where used as a concentrated spray a commercial preparation containing 50 per cent DDT was used.

DDD

An analog of DDT known as DDD or TDE, Dichlorodiphenyl-dichloroethane, was used in 5 per cent commercially prepared dusts, and a commercially prepared 50 per cent wettable powder for concentrated sprays.

Toxaphene

Toxaphene is a chlorinated camphene having the approximate empirical formula $C_{10}H_{10}Cl_8$, with the technical grade containing 67 to 69 per cent chlorine. Two dust formulations were used. One contained 10 per cent by weight of the technical material and the second contained a like amount plus 5 per cent DDT. In both cases the dusts contained 25 per cent sulfur.

Cryolite

A 50 per cent natural cryolite dust was used which contained 45 per cent of sodium fluoaluminate to which was added 25 per cent dusting sulfur.

CONTROL GIVEN BY VARIOUS INSECTICIDES

Integrated control program for entire season is advocated. New insecticides show promise as good substitutes for arsenic.

Experimental results from 1944 to 1947 have indicated that some of the recently developed insecticides offer exceptional promise as superior substitutes for calcium arsenate in the tomato insect control program. Experiments with these recently introduced insecticides were begun during 1944 when DDT first became available for agricultural testing, and have continued with increasing vigor to the present season.

Studies have also been conducted on the improvement of application of calcium arsenate. If calcium arsenate dust is used at the recommended rate of 15 to 25 pounds to the acre, satisfactory to excellent control of the corn earworm, armyworms, and hornworms can be expected. Against the tomato pinworm and the potato tuber moth, however, only indifferent control has been obtained. With the recent increase of tomato acreage in northern California came the concomitant demand for a more effective and less hazardous material to be used against all insects attacking tomato.

Advantages of Planning a Generalized Control Program

The problem of controlling tomato pests is probably best approached from the wider viewpoint of the progressional seasonal picture, rather than by giving a discussion of the control of individual insects. Repetition is thus avoided and the insect problems are seen in broad perspective. A well-integrated control program should consider all the important pests and provide protection to the crop throughout the summer and fall.

In general it has been found that the tomato mite is the first pest against which control measures must be directed. Between July 1 and 15, tomato fields should be dusted with sulfur. During this period hornworms, yellow-striped armyworms, and beet armyworms may be making their appearance, and where this occurs an effective insecticide should be used in conjunction with sulfur to control them.

During early August the important insects to control are the beet armyworm, yellow-striped armyworm, and hornworms. A suitable insecticide should be applied to check their damage. A material applied at this time will also control the few corn earworms which may be making their appearance. The insecticide should contain sulfur to further aid in the control of the tomato mite.

Early in September a third treatment is usually needed and is primarily di-

rected against the attack of the corn earworm, but it should also be effective against other armyworms and hornworms which are almost certain to be present. If damage by the tomato mite is not apparent, sulfur may be excluded from the third treatment.

The above timing schedule is one well suited to most of the northern area devoted to canning tomatoes, but the timing is not applicable to the early producing tomato sections of the San Joaquin Valley. Investigations in the latter regions have been rather limited but indicate that the control program should be put into operation in late May or June and continued as long as protection is considered necessary. However, application of insecticides at all times and in all areas should be based upon a knowledge of the insect pests present.

Investigations During 1946 Toward Eliminating Drift

The 1946 investigations have been reported by Michelbacher, *et al.* (1947), so only a brief summary will be presented here. The work was done with the following objectives in view.

1. To determine whether ground dusters could be equipped with hoods that would restrict drift.
2. To determine whether the incorporation of 2 and 4 per cent highly refined oil in calcium arsenate dust would settle it sufficiently to eliminate a serious drift problem.
3. To determine the feasibility of application and the effectiveness of calcium arsenate applied as a concentrated spray.
4. To determine the effectiveness of such new insecticides as DDT and DDD in controlling the important pests of tomato.

Hood ineffective

In order to study the efficiency of a hood in restricting drift, a five-row, tractor-mounted tomato duster was equipped with a seven-foot adjustable rigid hood supplied with end and side drapes. This equipment was used on several occasions, but even under favorable weather conditions the hood proved to be ineffective.

No drift control from oil

Where 2 and 4 per cent highly refined oil was incorporated in calcium arsenate dusts, little or no control of drift was observed. The oil had a tendency to keep the drift from boiling high into the air but not to settle it. Although the drift cloud failed to rise to any extent above the ground, it did drift from the field being treated.

Spray lessens drift problem

Investigations were conducted wherein calcium arsenate was used in a concentrated liquid spray the composition of which was as follows:

Oil emulsion	1 gallon
Water	3 gallons
Calcium arsenate	12 pounds

Where the above mixture was applied with a three-row compressed-air atomizing power sprayer (fig. 16), drift was eliminated and good control resulted. Where applied by airplane, no serious drift occurred, but the lack of precision shutoff valves at the nozzles made it impossible to confine the application to the field being treated. Further, the atomizing device was not adequate in that it could not be regulated accurately as to rate of delivery or to the most desirable particle size. Despite these disadvantages, fair control of caterpillars attacking tomatoes was obtained when an airplane was used.

New insecticides prove effective

In order to determine the effectiveness of some of the newer insecticides and several calcium arsenate mixtures against caterpillars attacking tomato, a series of experimental plots was laid out in a field near Woodland. There were seven treatments, and each was replicated 4 times in a randomized experiment. The individual plots averaged approximately 0.85 of

Table 1: TREATMENT AND PER CENT OF INFESTED TOMATOES IN THE REPLICATED EXPERIMENTAL COMMERCIAL PLOTS AT WOODLAND, 1946*

Treatment†	Approximate pounds per acre		Per cent of infested tomatoes											
			August 27 First picking			September 14 Second Picking			October 7 Third Picking			October 28 Fourth Picking		
	August 1 first application	August 23 second application	Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total
Check, 84 per cent sulfur	25	..	2.25	1.87	4.12	8.75	8.87	17.62	12.13	18.50	30.63	11.75	18.88	30.63
3 per cent DDT, 50 per cent sulfur‡	40	30	0.75	1.00	1.75	0.37	1.00	1.37	0.50	1.75	2.25	2.88	5.50	8.38
5 per cent DDT, 50 per cent sulfur	40	28	0.50	0.75	1.25	0.12	0.50	0.62	0.25	1.00	1.25	0.25	2.00	2.25
5 per cent DDD, 48 per cent sulfur	30	30	0.50	0.37	0.87	0.37	1.37	1.74	0.00	0.88	0.88	0.13	0.65	0.78
Calcium arsenate 75 per cent, sulfur 25 per cent	25	25	0.87	1.00	1.87	0.50	2.00	2.50	1.50	3.13	4.63	2.15	4.63	6.78
Calcium arsenate 75 per cent, sulfur 23 per cent, oil 2 per cent	25	25	0.75	1.00	1.75	0.37	1.25	1.62	1.75	3.75	5.50	1.65	4.50	6.15
Calcium arsenate 12 pounds, oil emulsion 1 gallon, water 3 gallons	24	24	1.00	0.75	1.75	0.62	1.50	2.12	1.00	1.13	2.13	1.13	4.25	5.38

* All applications made with a five-row power duster, except the calcium arsenate, oil emulsion, water concentrated spray which was applied with a three-row compressed-air sprayer.

† On July 13 entire field dusted with a mixture that contained 75 per cent calcium arsenate, and 25 per cent sulfur at the rate of 12 pounds per acre.

‡ Sulfur content reduced to 30 per cent in August 23 application.

an acre. The treatments, rate of application, and the control obtained of caterpillars infesting tomatoes are summarized in table 1. All the treatments resulted in good control. Slightly better control was obtained with DDD and DDT than with calcium arsenate. The calcium arsenate-oil-water concentrated spray proved to be as effective as the calcium arsenate dust treatments.

Special attention to Hornworms

The effect of the various treatments in controlling hornworms was observed. The per cent of damaged plants (that is, those on which feeding had occurred) as determined on September 12 was as follows:

Check	15.50 per cent
5 per cent DDD	0.00 per cent
3 per cent DDT	6.50 per cent
5 per cent DDT	1.75 per cent
Calcium arsenate plus sulfur	0.25 per cent
Calcium arsenate plus sulfur plus 2 per cent oil	0.37 per cent
Calcium arsenate-oil-water, concentrated spray	0.37 per cent

The above information was obtained by examining 200 plants from each plot for a total of 800 for each treatment. Observations made throughout the season indicated that the tomato hornworm made up the bulk of the hornworm population. The results show that DDD was more effective in controlling hornworms than was DDT.

Investigations During 1947 Tested New Insecticides

In 1947 testing of newer insecticides was continued, and considerable time was devoted to determining the effectiveness of several insecticides in controlling tomato insects when applied as liquid concentrated sprays. The concentrated sprays were applied by hand, ground machine, and by airplane. Dust mixtures were also applied by the above-mentioned methods. Extensive experiments were conducted at Woodland, Davis, Tracy, Westley, Patterson, and Merced. Some of the investigations were conducted on an experimental commercial scale, while others involved small plot replicated experiments.

Small plot replicated experiments

The small plot treatments were replicated four times in each experiment in a randomized plot arrangement. The small plot experiments were established not only to test the relative effectiveness of several insecticides but also to compare the merits of applying them as dusts versus concentrated sprays.

In two such experimental series, 10 different treatments were compared. One of these was located at Woodland and the other at Patterson. The information concerning treatments, rate and time of applications, and the control obtained of all species of caterpillars infesting tomatoes are given in table 2 for the Woodland experiment, and in table 3 for the Patterson experiment. The results indicate that DDT and DDD were more effective in controlling caterpillars infesting tomatoes than was calcium arsenate. Cryolite, 10 per cent Toxaphene, and calcium arsenate were in the same range of effectiveness.

Variations noted

As might have been expected, the dust mixture that contained 10 per cent Toxaphene and 5 per cent DDT resulted in excellent control. Calcium arsenate applied as a spray was about as effective as where applied as a dust. DDT and DDD applied as concentrated sprays or as dusts resulted in very satisfactory control, and there was little to choose between the two methods of application. In the case of DDT it appeared as if the sprays were slightly more effective than the dust, although the reverse occurred in the case of DDD. The differences, however, are not great, and probably are too small to be of any significance.

Table 2: TREATMENT, RATE OF APPLICATION, AND PER CENT OF INFESTED TOMATOES IN THE SMALL PLOT REPLICATED EXPERIMENT AT WOODLAND

Treatment*	Rate per acre in pounds		Per cent of infested tomatoes								
			September 15 First Picking			September 30 Second Picking			October 17 Third Picking		
	August 4 first application	September 10 second application	Severe	Super-ficial	Total	Severe	Super-ficial	Total	Severe	Super-ficial	Total
Check	....	....	10.3	7.3	17.6	8.6	7.6	16.2	8.5	4.1	12.6
5 per cent DDT, 25 per cent sulfur dust	28.0	24.0	1.3	1.6	2.9	1.6	2.4	4.0	0.9	0.7	1.6
50 per cent DDT wettable powder†	2.84	2.94	0.9	2.1	3.0	0.6	1.9	2.5	0.7	0.4	1.1
5 per cent DDD, 25 per cent sulfur dust	35.0	29.0	1.2	1.6	2.8	0.9	1.0	1.9	0.3	0.5	0.8
50 per cent DDD wettable powder†	2.67	3.05	2.3	2.1	4.4	0.6	2.0	2.6	0.9	0.1	1.0
Calcium arsenate dust‡	22.0	26.0	1.8	2.1	3.9	2.4	2.4	4.8	1.6	0.9	2.5
Calcium arsenate§	20.5	20.5	2.5	2.4	4.9	2.6	2.5	5.1	2.4	1.5	3.9
Cryolite (sodium fluoaluminate 45 per cent) dust‡	27.0	37.0	2.1	2.8	4.9	1.5	2.0	3.5	1.9	0.6	2.5
10 per cent Toxaphene, 25 per cent sulfur dust	25.0	27.0	0.9	2.4	3.3	2.3	2.5	4.8	1.7	0.4	2.1
10 per cent Toxaphene, 5 per cent DDT, 25 per cent sulfur dust	32.0	30.0	1.7	1.9	3.6	0.8	1.1	1.9	0.6	0.4	1.0

* On July 12 entire experimental area treated with a dust mixture containing 20 per cent calcium arsenate and 80 per cent dusting sulfur at 20 pounds per acre.
† Applied as a concentrated spray at the rate of 3 pounds to 10 gallons of water.
‡ Mixture used August 4 contained 25 per cent dusting sulfur.
§ Applied as a concentrated spray at the rate of 22 pounds to 10 gallons of water.

Table 3: TREATMENT, RATE OF APPLICATION, AND PER CENT OF INFESTED TOMATOES IN THE SMALL PLOT REPLICATED EXPERIMENT AT PATTERSON

Treatment*	Rate per acre in pounds		Per cent of infested tomatoes					
			September 9 First picking			October 7 Second picking		
	July 28 first application	Sept. 2 second application	Severe	Superficial	Total	Severe	Superficial	Total
Check	....	....	3.87	1.25	5.12	5.12	4.12	9.24
5% DDT, 25% sulfur dust	34.5	30.0	1.12	0.75	1.87	0.25	1.62	1.87
50% DDT wettable powder†	3.5	3.5	0.62	0.12	0.74	0.50	0.88	1.38
5% DDD, 25% sulfur dust	26.0	37.0	0.62	0.25	0.87	0.12	1.12	1.24
50% DDD wettable powder†	3.5	3.2	1.00	0.50	1.50	0.62	0.62	1.24
Calcium arsenate dust‡	32.0	22.0	0.50	0.12	0.62	1.00	1.88	2.88
Calcium arsenate§	22.0	30.5	0.62	0.25	0.87	1.75	0.50	2.25
Cryolite (sodium fluoaluminate 45%), 25% sulfur dust	32.0	37.5	0.75	0.75	1.50	1.62	1.88	3.50
10% Toxaphene, 25% sulfur dust	30.5	33.5	0.75	0.88	1.63	1.88	1.62	3.50
10% Toxaphene, 5% DDT, 25% sulfur dust	25.5	34.5	0.00	0.62	0.62	0.50	0.00	0.50

* On July 5 entire experimental area treated with a dust mixture containing 25 per cent commercial calcium arsenate and 75 per cent dusting sulfur at 25 pounds per acre.
† Applied as a concentrated spray at the rate of 3 pounds to 10 gallons of water.
‡ Dust mixture applied July 28, contained 25 per cent dusting sulfur.
§ Applied as a concentrated spray at the rate of 22 pounds to 10 gallons of water.

Experimental commercial tests

A large number of commercial applications of insecticides were made. The treatments were not replicated in any given field, although many of them were repeated in several fields throughout the tomato-producing region. The treatments, methods of application, pounds of insecticide used, dates of application, and the per cent of infested tomatoes in the harvested crop are given in the tables that cover this phase of the investigation. The information for the experiment at Woodland is given in table 4, for Davis in table 5, for Westley in table 6, and for Patterson in table 7. No effort will be made to analyze individually the information in each of these tables, but instead, comments will be made concerning the overall picture obtained.

In substantiation of the small plot experiments, DDT and DDD proved to be much more effective than was calcium arsenate. In general, calcium arsenate proved to be more effective where applied as a dust than where applied as a concentrated spray. DDT and DDD were of nearly equal effectiveness. In some fields DDT held a slight advantage, while the reverse was true in others. However, the over-all picture slightly favors DDT, but the difference is probably too small to be of any real significance.

If DDT and DDD dusts and concentrated sprays are compared, it is seen that the former were the most effective, except where the concentrated sprays were applied with a Naconizer. The Naconizer was used for all applications in the experiment located at Woodland only (table 4). The superior control obtained may have been the result of a number of factors. Although there were three applications of dusts and concentrated sprays, the total amount of active insecticide applied by

Table 4: TREATMENT AND PER CENT OF INFESTED TOMATOES IN EXPERIMENTAL COMMERCIAL BLOCKS AT WOODLAND

Method of application and treatment	First application		Second application		Third application	
	Date	Approximate pounds per acre	Date	Approximate pounds per acre	Date	Approximate pounds per acre
Liquid application by Naconizer:						
50 per cent DDT wettable powder*	July 11	3.0	Aug. 6	3.0	Sept. 4	3.0
50 per cent DDD wettable powder*	July 11	3.0	Aug. 6	3.4	Sept. 4	3.2
Liquid application by airplane†:						
50 per cent DDT wettable powder*	......	....	Aug. 6	3.0	Sept. 4	3.0
50 per cent DDD wettable powder*	......	....	Aug. 6	3.0	Sept. 4	3.0
Calcium arsenate‡	......	....	Aug. 6	25.0	Sept. 4	25.0
Dusted by ground rig:						
5 per cent DDT, 50 per cent sulfur	July 13	18.0	Aug. 8	23.0	Sept. 10	22.0
5 per cent DDD, 50 per cent sulfur	July 13	18.0	Aug. 8	19.0	Sept. 10	23.0
Calcium arsenate	July 12	20.0	Aug. 8	23.0	Sept. 10	22.0

Method of application and treatment	Per cent of infested tomatoes											
	September 15 First picking			September 30 Second picking			October 16 Third picking			October 30 Fourth picking		
	Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total
Liquid application by Naconizer:												
50 per cent DDT wettable powder*	0.25	1.00	1.25	1.25	1.25	2.50	0.00	0.28	0.28	0.50	1.00	1.50
50 per cent DDD wettable powder*	0.00	0.75	0.75	2.50	3.00	5.50	0.57	0.43	1.00	0.25	0.25	0.50
Liquid application by airplane†:												
50 per cent DDT wettable powder*	2.25	3.25	5.50	3.25	2.50	5.75	0.86	0.42	1.28	0.75	1.00	1.75
50 per cent DDD wettable powder*	1.75	2.75	4.50	3.25	2.50	5.75	1.00	1.00	2.00	1.00	0.75	1.75
Calcium arsenate‡	4.75	3.75	8.50	8.25	6.25	14.50	3.86	2.14	6.00	3.00	2.50	5.50
Dusted by ground rig:												
5 per cent DDT, 50 per cent sulfur	1.50	1.75	3.25	2.00	0.75	2.75	1.14	0.86	2.00	0.50	1.25	1.75
5 per cent DDD, 50 per cent sulfur	1.25	1.00	2.25	2.25	2.25	4.50	0.57	1.00	1.57	0.25	2.00	2.25
Calcium arsenate	3.25	4.00	7.25	5.75	4.25	10.00	3.42	1.86	5.28	2.25	3.50	5.75

* Applied as a concentrated spray at the rate of 3 pounds to 10 gallons of water; 15 pounds wettable sulfur added to the mixture applied July 11.
† On July 12 the airplane plots were treated with a dust mixture containing 20 per cent calcium arsenate and 80 per cent dusting sulfur at the rate of 20 pounds per acre with a ground duster.
‡ Applied as a concentrated spray at the rate of 25 pounds to 10 gallons of water.

Table 5: TREATMENT AND PER CENT OF INFESTED TOMATOES IN EXPERIMENTAL COMMERCIAL BLOCKS AT DAVIS

Treatment*	Approximate rate per acre in pounds and method of application		Per cent of infested tomatoes											
	July 30 first application by Naconizer	August 28 second application by airplane	September 1 First picking			September 18 Second picking			October 3 Third picking			October 14 Fourth picking		
			Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total
Check	....	....	26.75	18.00	44.75	40.50	39.00	79.50	17.75	18.00	35.75	41.66	23.66	65.32
Dusted:														
5 per cent DDT, 50 per cent sulfur	30.0	30.0	0.94	1.17	2.11	0.33	1.66	2.00	0.25	1.00	1.25	0.00	0.33	0.33
5 per cent DDD, 85 per cent sulfur; no sulfur second application	30.0	30.0	1.85	1.17	3.02	0.66	1.66	2.30	0.25	0.25	0.50	0.00	0.66	0.66
Calcium arsenate†	26.0‡	25.0	1.75	2.50	4.25	2.33	2.33	4.66	2.25	2.00	4.25	4.33	3.00	7.33
Sprayed:														
50 per cent DDT wettable powder§	3.0	3.0	1.63	1.63	3.26	0.66	1.33	2.00	0.50	0.25	0.75	0.00	0.33	0.33
50 per cent DDD wettable powder§	3.0	3.0	2.10	2.57	4.67	1.33	4.00	5.33	1.25	1.25	2.50	0.00	0.00	0.00
Calcium arsenate¶—Plot dusted with sulfur 25 pounds per acre July 29	24.0	24.0	3.92	4.85	8.77	13.33	14.00	27.33	6.00	8.50	14.50	4.33	3.00	7.33

* On July 1 entire field, with exception of check, treated with a dust mixture containing 25 per cent calcium arsenate and a 75 per cent dusting sulfur at 20 pounds per acre.
† Dust mixture applied July 30 contained 20 per cent dusting sulfur.
‡ Calcium arsenate applied with a ground power duster.
§ Applied as a concentrated spray at the rate of 3 pounds to 10 gallons of water; 15 pounds of wettable sulfur added to the mixture applied July 30.
¶ Applied as a concentrated spray at the rate of 25 pounds commercial calcium arsenate to 10 gallons water.

Table 6: TREATMENT AND PER CENT OF INFESTED TOMATOES IN EXPERIMENTAL COMMERCIAL BLOCKS AT WESTLEY

(All applications by airplane)

Treatment*	First application		Second application		Per cent of infested tomatoes											
					September 5 First picking			September 25 Second picking			October 15 Third picking			October 22 Fourth picking		
	Date	Approx. pounds per acre	Date	Approx. pounds per acre	Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total	Severe	Superficial	Total
Dusts:																
5 per cent DDT, 50 per cent sulfur	Aug. 15	30	Sept. 19	30	0.25	1.50	1.75	0.75	2.50	3.25	2.50	1.00	3.50	0.25	1.25	1.50
5 per cent DDD, 50 per cent sulfur	Aug. 15	30	Sept. 20	30	1.00	1.25	2.25	4.50	1.50	6.00	0.50	1.50	2.00	0.75	2.00	2.75
75 per cent calcium arsenate, 25 per cent sulfur	Aug. 21	24	Sept. 23	24.0	1.00	1.25	2.25	8.75	4.00	12.75	2.50	1.50	4.00	1.00	0.80	1.80
Concentrated sprays:																
50 per cent wettable DDT†	Aug. 12	3.0	Sept. 5	3.0	1.25	1.75	3.00	1.25	2.00	3.25	1.00	0.00	1.00	0.25	1.50	1.75
50 per cent wettable DDD†	Aug. 12	3.0	Sept. 5	3.0	1.75	0.50	2.25	2.25	0.25	2.50	0.50	0.00	0.50	0.50	2.25	2.75
Commercial calcium arsenate‡	Aug. 12	24.0	Sept. 5	24.0	1.25	1.25	2.50	1.75	1.25	3.00	2.00	0.50	2.50	1.00	2.25	3.25

* On June 15 entire field treated with a dust mixture containing 50 per cent calcium arsenate and 50 per cent dusting sulfur at the rate of 17 pounds per acre, and on July 15, entire field treated with a dust mixture containing 25 per cent calcium arsenate and 75 per cent dusting sulfur at 21 pounds per acre.

† Used at the rate of 3 pounds to 10 gallons of water.

‡ Used at the rate of 24 pounds to 10 gallons of water.

Table 7: TREATMENT, RATE OF APPLICATION, AND PER CENT OF INFESTED TOMATOES IN EXPERIMENTAL COMMERCIAL BLOCKS AT PATTERSON

(All applications by airplane)

Treatment*	Rate per acre in pounds		Per cent of infested tomatoes					
			September 25 First picking			October 15 Second picking		
	First application August 12	Second application Sept. 5	Severe	Superficial	Total	Severe	Superficial	Total
50% DDT wettable powder†	3.0	3.0	1.00	3.50	4.50	1.00	0.50	1.50
50% DDD wettable powder†	3.0	3.0	1.50	1.75	3.25	0.00	0.50	0.50
Commercial calcium arsenate.‡	24.0	24.0	2.00	2.75	4.75	1.50	0.50	2.00

* On July 15 entire field treated with a dust mixture containing 50 per cent calcium arsenate and 50 per cent dusting sulfur.
† Used at the rate of 3 pounds to 10 gallons of water.
‡ Used at the rate of 24 pounds to 10 gallons of water.

the Naconizer was greater than the amount of dust applied by the duster. Likewise, the treated plants in the Naconizer plots received a greater amount of actual insecticide than did the treated plants in the airplane plots. However, the amount of insecticide applied in both cases during the most critical period was nearly the same. Here the difference in the effectiveness could be due to the Naconizer giving better coverage, more desirable particle size, and also a higher deposit due to the fact that the nozzles directed the spray to the vines. An airplane, on the other hand, applies a spray over the entire field, and cannot concentrate it on the growing plants.

Abundance of caterpillars present

In 1947 the infestation of caterpillars attacking tomatoes was one of the most severe encountered during any recent year. In spite of the destructive population, most of the treatments resulted in very satisfactory control. The severity of the infestation is clearly indicated by the fact that in the Davis experiment nearly 80 per cent of the fruit from the check plot (table 5) on the second picking was infested.

The yellow-striped armyworm was particularly destructive in this field as it was over much of the rest of the tomato-producing region. One particular source of annoyance was migrations of this pest from newly cut alfalfa to tomato fields. These migrations were frequently extensive but tomato fields could be protected by a barrier of 5 per cent DDT or DDD dust a foot to 18 inches wide, placed between them and the source of the migration.

The corn earworm population reached a destructive level and, at least in the San Joaquin Valley, was more abundant than usual. Large flights of moths from mature or harvested bean fields to tomato fields during the latter part of August and September resulted in serious infestations in tomatoes. In the experimental field at Patterson infestation of small developing fruit by the corn earworm rose from one half of one per cent on August 22 to 30 per cent on September 16. Yet despite this heavy influx, excellent control was obtained in the treated portion of the field (table 7).

The beet armyworm, which is usually very destructive, was less abundant than usual during the 1947 season.

One of the prime reasons for establishing an experimental series at Merced was to determine the effectiveness of DDT and DDD against the tomato pinworm. A serious infestation of this pest failed to develop in the experimental field. How-

ever, what information was obtained indicated that these two insecticides were effective against this pest. Neiswander (1945) has reported DDT as giving satisfactory control of the tomato pinworm.

In none of the fields surveyed was the potato tuber moth observed doing damage and as a result no experiments were conducted on the control of this insect with the newer insecticides.

Hornworm control

The tomato hornworm and the tobacco hornworm were present throughout the important tomato-producing regions of northern California. In the absence of control measures, serious damage to tomatoes would have occurred, particularly in many of the fields in the warmer interior valleys. The relative effectiveness of several insecticides in controlling these pests was obtained in two small-plot replicated experiments. One of these was located at Davis and the other at Patterson. The treatments and the results obtained are given in table 8.

The insecticides involved in the experiment at Davis were DDT, DDD, and calcium arsenate. DDD both as a dust and concentrated spray resulted in excellent control. Where DDT was applied as a concentrated spray, satisfactory control

Table 8: COMPARATIVE EFFECTIVENESS OF SEVERAL TREATMENTS IN CONTROLLING HORNWORMS IN EXPERIMENTAL PLOTS AT DAVIS AND PATTERSON

Treatment	First application		Second application		Per cent of injured plants on Sept. 10
	Date	Approx. pounds per acre	Date	Approx. pounds per acre	
Davis experimental plots:					
Check	....	....	....	....	65.0
5% DDT, 25% sulfur	July 16	36.0	August 9	34.0	28.0
50% DDT wettable powder*	July 16	2.9	August 9	3.0	2.3
5% DDD, 48% sulfur	July 16	29.0	August 9	29.0	0.0
50% DDD wettable powder*	July 16	3.0	August 9	3.0	0.0
75% calcium arsenate, 25% sulfur dust	July 16	36.3	August 9	21.2	2.0
Patterson experimental plots:					
Check	....	....	....	....	23.0
5% DDT, 25% sulfur dust	July 28	34.5	September 2	30.0	15.0
50% DDT wettable powder*	July 28	3.5	September 2	3.5	1.9
5% DDD, 25% sulfur dust	July 28	26.0	September 2	37.0	0.8
50% DDD wettable powder*	July 28	3.5	September 2	3.2	0.5
Calcium arsenate dust‡	July 28	32.0	September 2	22.0	0.9
Calcium arsenate†	July 28	22.0	September 2	30.5	0.9
Cryolite (sodium fluoaluminate 45%), 25% sulfur dust	July 28	32.0	September 2	37.5	20.0
10% Toxaphene, 25% sulfur dust	July 28	30.5	September 2	33.5	2.6
10% Toxaphene, 5% DDT, 25% sulfur dust	July 28	25.5	September 2	34.5	1.4

* Applied as a concentrated spray at the rate of 3 pounds to 10 gallons of water.
† Applied as a concentrated spray at the rate of 22 pounds of commercial calcium arsenate to 10 gallons of water.
‡ Material applied July 28 contained 25 per cent dusting sulfur.

was obtained, but the results were unsatisfactory where it was applied as a dust. Where the dust was used, 28 per cent of the plants were injured as compared to 2.3 per cent for the concentrated spray and 65 per cent for the check.

In the experiment at Patterson, DDT, DDD, calcium arsenate, Cryolite, and Toxaphene were used. All of these produced satisfactory control, except for the Cryolite and the DDT dusts. In this experiment 23 per cent of the plants in the check plots were injured, 20 per cent in the Cryolite treatment, 15 per cent in the DDT dust treatment, and 0.0 per cent in the DDD dust treatment. Where DDT was applied as a concentrated spray, only 1.9 per cent of the plants were injured. Other observations were made that clearly indicated that a 5 per cent DDT dust was somewhat ineffective against hornworms, but where DDT was applied as a concentrated spray, satisfactory control resulted.

In the course of these investigations it has been observed that the tobacco hornworm is more susceptible to DDT than is the tomato hornworm. However, if the coverage is sufficient, the tomato hornworm is killed. White (1945) reported that in field experiments at Florence, S.C., and Oxford, N.C., the application of a 5 or 10 per cent DDT dust did not give a satisfactory reduction of *Protoparce sexta*. In laboratory tests the fifth instar of *P. sexta* was not affected by a 10 per cent dust but the same instar of *P. quinquemaculata* succumbed readily. White (1946) reported that *P. sexta* in Tennessee, South Carolina, and North Carolina was not satisfactorily controlled with up to 30 pounds per acre of a 10 per cent dust, but in southern California it was successfully controlled by a 10 per cent DDT, 25 per cent sulfur dust in pyrophyllite. Wilcox and Howland (1946), in southern California reported undiluted calcium arsenate to be superior to 10 per cent DDT dust in the control of hornworms.

Apparently the reason for the effectiveness of the concentrated DDT spray over the dust is due to the relatively higher deposit of material built up on the periphery of the vines by the spray, the region where hornworms feed the most.

Miscellaneous experiments

A series of experiments were conducted to determine whether the addition of 1 or 2 per cent of a highly refined mineral oil would increase the insecticidal effectiveness of DDT dusts. The results of this investigation indicated that the addition of the oil had little or no beneficial effect. In conjunction with the above experiment, a concentrated DDT emulsion spray was tested. The control obtained was superior to that obtained with a dust, but the experiment was too limited to be conclusive.

Tomato mite control

The control of the tomato mite is not difficult where dust formulations are used. If necessary, sulfur can be added to the mixtures. However, with the concentrated sprays, mite control presents a problem. It is possible to add a wettable sulfur to the concentrated spray mixture as was done in the Woodland experiment (table 4) where the applications were made with a Naconizer. Although satisfactory results were obtained, it was difficult to prepare the concentrated spray material in a suitable manner to insure proper application. It would appear that where concentrated sprays are used, the mite control program might be undertaken as a separate operation. It is possible that a thorough application of a sulfur dust early in July would in many cases adequately control the pest for the entire season. Observations have shown that DDT has no controlling action upon the tomato mite. In fact some evidence was obtained that applications of a concentrated DDT spray may encourage an increase in the mite population.

In the Woodland experiment, light and spotty infestations of the tomato mite developed in late August and September in

some of the plots that received concentrated spray applications of DDT and DDD. However, in none of these did the mite become destructive, and no evidence of their reducing the yield could be detected.

Cultural Methods Can Aid Control of Caterpillars

The destruction of crop refuse is a sanitary measure that should be practiced. It is particularly important that this be done in regions where the tomato pinworm or

Fig. 18. ***Hyposoter exiguae*** **(Vier.), an important hymenopterous larval parasite of the corn earworm: *A*, adult enlarged three times; *B*, adult corn earworm attached (natural size).**

the potato tuber moth is likely to be a problem. Where the pinworm is a pest, growing of an early and late season crop should be avoided if this is at all possible. There is danger of the pest developing a pupulation on the early crop that will serve as a focus of infestation for the later one. If two crops are grown, the first should be destroyed by burning or plowing under just as soon as harvest is completed. Elmore and Howland (1943) reported on the importance of cultural methods in the control of this pest.

The practice of following potatoes with tomatoes should be avoided. As previously indicated, serious infestations of the potato tuber moth in tomatoes is usually associated with potato culture. Most extensive damage by this pest has usually been encountered in those fields where volunteer potato plants have been growing.

Infestations by the corn earworm on tomatoes are likely to be most severe in areas where more preferred hosts such as sweet corn and beans are grown in fair abundance. While these preferred crops are in an attractive state of growth for the adult moths to oviposit upon, there may be but a light infestation of corn earworms in tomatoes. However, the moths that emerge from these fields after the crops are mature may migrate to tomatoes and give rise to destructive populations. Infestations in tomatoes from such sources do not usually arise until late August or September. Although there is not much a grower can do to avoid these migrations, he can encourage the destruction of crop refuse as soon as the preferred hosts are harvested. This is of particular importance in the case of sweet corn.

Early maturity

Because the corn earworm infestation becomes more acute as the season advances, a grower should adopt those cultural practices that will enable him to bring his crop to maturity at the earliest possible date.

Natural Enemies of Pests Are of Help in Control

Caterpillars infesting tomato are subject to the attack of a number of parasites. The full value of these parasites in reducing the damage done by the several species of caterpillars is difficult to determine. There is little question but that they are extremely important and may be responsible in a large measure for some species of caterpillars not reaching a destructive level every year. In this regard Elmore and Howland (1943) reported "Parasites have undoubtedly been an important factor [in southern California] in the gradual decrease in pinworm abundance since 1936, the period of maximum abundance, until 1941, when a low point in degree of pinworm injury was reached."

The most important parasite attacking the corn earworm is *Hyposoter exiguae* (Vier.) (fig. 18). It attacks the small larvae, and frequently a large proportion of the population is parasitized. When abundant, the adults of this parasite may be seen flying about the tomato vines. Observations have indicated that this parasite plays an important role in limiting the damage done by the corn earworm. This parasite also attacks the yellow-striped armyworm, and may be one of the important natural factors that determine the abundance of this annoying pest.

The action of the many parasites upon their host, and the influence they exert in regulating populations is a subject that is in need of thorough investigation. It is important that insecticidal control programs be developed that will have the least adverse effect upon these important natural enemies. Control programs that will supplement the work of the natural parasites and predators are the goal.

Fig. 19. Injury to tomato leaflets caused by spraying with DDT, 1 pound per 100 gallons: *A*, normal leaflet; *B, C*, sprayed leaflets showing interveinal and marginal yellowing; *D*, sprayed leaflet in final stages of injury, showing tan-colored, papery drying-out of the marginal tissues.

Possibility of Injury to Tomato Plants from DDT

Under certain conditions DDT has been known to cause injury to tomato plants. Gardner, *et al.* (1945), reported serious injury to greenhouse tomatoes that were treated with DDT. The nature of the injury to the leaflets is illustrated in figure 19. The following year Gardner and Michelbacher (1946) again reported injury to tomatoes grown under glass when treated with DDT. Tanada, *et al.* (1947), reported DDT injurious to tomato in Hawaii, and plant injury has been reported from New Jersey by the United States Department of Agriculture (1945). Baker and Porter (1945) stated that 25

pounds of actual DDT per acre applied to the soil resulted in injury to tomatoes planted on the treated land. Lange and Carlson (unpublished) conducted investigations at Davis which showed that tomatoes were injured when planted on land treated with either 20 or 40 pounds of DDT to the acre.

The authors have observed no injury to tomato under field conditions where DDT has been applied at the rates used in these investigations. Wilcox and Howland (1946) reported no injury from three applications of 10 per cent DDT at 30 pounds per acre in southern California. It appears that there is not a great deal of danger of serious plant injury from the direct application of DDT. However, very little information is available as to the rate of decomposition of DDT in the soil, and if this process should be extremely slow there may be some danger of the insecticide accumulating in the soil to a dangerous level. In this connection Fleming and Maines (1947), who used 25 pounds of actual DDT per acre, showed that the effectiveness of DDT against the third instar larvae of the Japanese beetle did not change significantly in various types of soils during 128 weeks.

STUDIES OF INSECTICIDAL RESIDUES[2]

Tests made to determine effectiveness of usual washing methods in removing residues from tomatoes used for canning.

Since the Federal Food and Drug Administration has announced no tolerance for the presence of DDT and related compounds in canned foods, it is imperative that residual amounts of these compounds be effectively removed before the raw product is canned. The purpose of this phase of the investigation was to determine the effectiveness of removal of DDT and DDD from tomatoes by washing methods similar to those used in commercial canneries.

Further, since there is a likelihood of calcium arsenate being widely used as a concentrated spray for the control of caterpillars attacking tomato, it was deemed desirable to investigate the effectiveness of removal of calcium arsenate residue from tomatoes where fields had been treated by this method. For previous studies on the residue of calcium arsenate dusts, see Michelbacher and Essig (1935) and Michelbacher, *et al.* (1940).

Tomato samples for analysis were obtained from treatments in the experimental fields. The fruit samples were picked the same day that the final application of insecticides was made and therefore would probably have the maximum deposit of residue. Samples were taken from fields that had been treated with DDT and DDD dusts or concentrated sprays, and from fields where calcium arsenate had been applied as a concentrated spray. Residue determinations were made where the above insecticides had been applied with hand dusters, hand sprayers, ground power dusters, with a Naconizer, airplane dusters, and airplane sprayers. This was done in order to study residue removal under all the different methods of application. The treatments, method and dates of application, pounds of insecticides used, and the date samples were picked for the residue analysis are given in table 9 for DDT and DDD programs, and in table 10 for the calcium arsenate programs.

Experimental Procedure

One box containing approximately 45 pounds of tomatoes, representing each of the insecticide field treatments, was used in this study. Duplicate samples of the unwashed tomatoes representing from 15

[2] This section was prepared by F. C. Lamb of the National Canners' Association Laboratories.

to 20 tomatoes (about 2 kilograms) for each separate determination were set aside for the analysis of DDT, DDD, or arsenic. The remaining tomatoes were then given the following washing treatment:

1. Immersed in a tank of clean water and agitated gently for 1 minute.
2. Spread out in a single layer on a screen and sprayed for 30 seconds, using the full pressure of the city water supply. The tomatoes were then turned over and sprayed for an additional 30 seconds.

Duplicate samples of the washed tomatoes were then prepared for analysis, as before. The remaining tomatoes were put through a "Victorio" home juicer and samples of the juice and of the residue preserved with formaldehyde. The reremainder of the juice was canned in picnic cans by the following procedure:

The juice was heated to 210° F. in enamel buckets and held at this temperature for several minutes. It was then filled into picnic cans and the cans quickly sealed. They were then allowed to stand for about 3 minutes, following which they were cooled to room temperature in a tank of water.

Methods of Analysis

The raw samples treated with DDT or DDD were extracted with chemically pure benzene (thiophene free) according to the method described by Wichmann, *et al.* (1946). An aliquot of the benzene extract was set aside in the refrigerator for determination of DDT and DDD by the Schechter-Haller method and the remainder was used for determination by the total chlorine method. Both methods were performed as outlined by Wichmann, *et al.*, with minor modifications.

In the Schechter-Haller method both DDT and DDD were calculated from the same calibration curve plotted from chemically pure DDT (Eimer and Amend) using the Evelyn colorimeter equipped with a 580 mu filter. Schechter and Haller (1944) have reported specific extinction coefficients (g./cm.) for p p′ DDT at 600 mu and for p p′ DDD at 598 mu of 48.0 and 38.7 respectively. Toxicity studies have shown that the p p′ isomer of DDT is considerably more toxic than the o p′ isomer. These data indicate that DDD produces approximately 80 per cent as much color as DDT. This correction factor was not applied to the present results since it was not known how closely the extinction coefficients of Schechter and Haller would apply to the experimental conditions obtained in these studies. No pure DDD was available for plotting an absorption curve.

No effort was made to determine the o p′ and p p′ isomers of DDT individually since it was felt that the calibration curve plotted with chemically pure DDT was reasonably close to the curve that would be obtained with technical DDT, and that the additional refinement of the method was not justified. Readings taken with the 515 mu and 440 mu filters showed the above assumption to be valid.

The samples of juice and of the residue from juice extraction were analyzed for DDT and DDD by the Schechter-Haller method only. The samples were extracted with benzene according to the directions of Tressler (1947).

Arsenic was determined by the Cassil and Wichmann method (1939). On all the raw samples except for those from the Davis plot the whole tomatoes were ground in a Waring Blendor until homogeneous, and arsenic was determined on the ground mixture. On the raw samples from the Davis plot the tomatoes were peeled and cored by hand and the peelings and cores ground in the Waring Blendor and analyzed for arsenic. The results were calculated on the basis of the original tomatoes.

Residues of DDT, DDD

In table 9 are shown the results obtained on the DDT and DDD treated samples. The samples were analyzed both by

Table 9: DDT AND DDD RESIDUES ON TOMATOES FOLLOWING VARIOUS TREATMENTS

Treatment† and locality	1st application		2d application		3d application		Method of application	Date sample picked	Residue of DDT or DDD in parts per million*			
	Date	Approx. pounds per acre	Date	Approx. pounds per acre	Date	Approx. pounds per acre			Before washing	After washing	Juice	Residue
Experimental Commercial Blocks—Davis:												
Check	....	....	....	....	....	....	....	Aug. 28	0.10	0.03	....	....
50% DDT wettable powder	July 30	3.0	Aug. 28	3.0	....	....	1st Naconizer 2d airplane	Aug. 28	0.90	0.20	....	....
50% DDD wettable powder	July 30	3.0	Aug. 28	3.0	....	....	1st Naconizer 2d airplane	Aug. 28	0.50	0.10	....	....
5% DDT, 50% sulfur	July 30	30.0	Aug. 28	30.0	....	....	1st Naconizer 2d airplane	Aug. 28	0.20	0.20	....	....
5% DDD, 85% sulfur	July 30	30.0	Aug. 28	30.0	....	....	1st Naconizer 2d airplane	Aug. 28	0.20	0.10	....	....
Experimental Commercial Blocks—Woodland:												
Check	....	....	....	....	....	....	....	Sept. 4	0.15	0.10	....	....
50% DDT wettable powder	Aug. 6	3.0	Sept. 4	3.0	....	....	airplane	Sept. 4	0.60	0.40	....	...
50% DDT wettable powder	July 11	3.0	Aug. 6	3.0	Sept. 4	3.0	Naconizer	Sept. 4	1.50	0.70	0.10	4.3
50% DDD wettable powder	Aug. 6	3.0	Sept. 4	3.0	....	....	airplane	Sept. 4	0.50	0.30	....	....
50% DDD wettable powder	July 11	3.0	Aug. 6	3.4	Sept. 4	3.2	Naconizer	Sept. 4	1.30	0.50	0.05	4.2
5% DDT, 50% sulfur	July 13	18.0	Aug. 8	23.0	Sept. 10	22.0	ground duster	Sept. 10	0.50	0.20	....	....
5% DDD, 50% sulfur	July 13	18.0	Aug. 8	19.0	Sept. 10	23.0	ground duster	Sept. 10	0.50‡	0.30‡	....	....

Treatment† and locality	1st application		2d application		3d application		Method of application	Date sample picked	Residue of DDT or DDD in parts per million*			
	Date	Approx. pounds per acre	Date	Approx. pounds per acre	Date	Approx. pounds per acre			Before wash-ing	After wash-ing	Juice	Residue
Small Plot Replicated Experiment—Patterson:												
Check	....	....	....	....	....	....	....	Sept. 2	0.05	0.04	....	....
50% DDT wettable powder	July 28	3.5	Sept. 2	3.5	....	....	hand sprayer	Sept. 2	1.70	0.50	0.00	2.7
50% DDD wettable powder	July 28	3.5	Sept. 2	3.2	....	....	hand sprayer	Sept. 2	1.00	0.50	0.00	2.9
5% DDT, 25% sulfur	July 28	34.5	Sept. 2	30.0	....	....	hand duster	Sept. 2	0.40	0.10	....	....
5% DDD, 25% sulfur	July 28	26.0	Sept. 2	37.0	....	....	hand duster	Sept. 2	0.60	0.20	....	....
Small Plot Replicated Experiment—Woodland:												
Check	....	....	....	....	....	....	....	Sept. 10	0.10	0.10	....	....
5% DDT, 2% oil	Aug. 6	28.0	Sept. 10	29.0	....	....	hand duster	Sept. 10	0.60	0.30	....	....
25% DDT emulsion	Aug. 6	1.3§	Sept. 10	1.65§	....	....	hand sprayer	Sept. 10	1.00	0.50	0.03	2.6

* Determined by the Schechter-Haller method. DDD calculated as DDT based on calibration curve obtained with C.P. DDT.
† DDT and DDD wettable powders applied as concentrated sprays at the rate of 3 pounds to 10 gallons of water.
‡ Determined by the total chlorine method.
§ Actual amount of DDT.

the total chlorine method and by the Schechter-Haller method, except for the 5 per cent DDD dust treatment in the commercial blocks at Woodland, in which case only the total chlorine method was used. Only the results obtained by the Schechter-Haller method are shown with the above exception for the reason that these results are thought to be more reliable. Although agreement between the two methods was satisfactory in many of the samples, occasional samples gave definitely higher results by the total chlorine method. Since these high results could not be explained by any logical means, it was concluded that they probably were caused by the chance presence in the sample of other chlorine-containing compounds. Carter (1947) suggests that the Schechter-Haller method, by reason of its greater specificity, should be used in all cases where it is suspected that the total chlorine determinations may not be valid.

The maximum amount of DDT and DDD residue found by the Schechter-Haller method before washing was 1.7 ppm and the minimum was 0.2 ppm in the samples treated with these materials.

Except in one instance the amount of DDT and DDD present after washing was not in excess of 0.5 ppm and in this instance the residue amounted to only 0.7 ppm.

DDT and DDD were determined in the samples of juice and residue preserved with formaldehyde which contained 0.5 ppm or more residue on the washed tomatoes. These results were so low, particularly on the juice, that it was not considered necessary to test the remainder of the samples nor of the samples of processed juice.

The amount of DDT or DDD in the juice prepared from the washed tomatoes was negligible in every instance, but there was a considerable concentration of the DDT or DDD in the residue from juicing operations. This concentration is undoubtedly the result of the extreme insolubility of DDT and to its affinity for certain portions of the residue material.

This concentration of DDT and DDD in the residue, or pumice, indicates that a potential hazard may exist if this material is dried for use as a cattle feed. Tomato pulp made by re-extraction of the residue from partial extraction of tomato juice may also contain higher amounts of DDT and DDD residues than would be present in juice extracted from whole tomatoes. Similarly, it may be reasoned that puree made from cores and peelings might contain increased amounts of DDT and DDD residues.

Conclusions

Examination of the data in respect to the treatment variables employed in these studies leads to the following conclusions:

1. The concentrations of DDT and DDD on the unwashed tomatoes varied from 0.2 to 1.7 parts per million (ppm) and on the same fruit after washing, from 0.1 to 0.7 ppm, when determinations were made by the Schechter-Haller method. Juice prepared from these washed tomatose contained 0.1 ppm or less of DDT or DDD. The juice residue contained from 2.7 to 4.3 ppm DDT or DDD.

2. DDT and DDD residues were higher when the material was applied as a spray than when it was applied as a dust, and higher when the insecticide was applied by ground dusting or spraying than when applied by airplane.

3. The amount of residue obtained as a result of airplane dusting was less than that obtained by ground dusting.

4. DDT residues appeared to be slightly higher than DDD residues in most instances. These differences might have been due in part to the method of calculation of the results by the Schechter-Haller method; however, results obtained by the total chlorine method, in which calculation was based on the total number of chlorine atoms of DDT and DDD, gave the same indication in all samples which were not completely out of line with the Schechter-Haller results.

Table 10: ARSENIC RESIDUES ON TOMATOES TREATED WITH CALCIUM ARSENATE AS A CONCENTRATED SPRAY*

Treatment and locality	First application		Second application		Methods of application	Date samples picked	Residual Arsenic as As_2O_3 in parts per million†			
	Date	Approx. pounds per acre	Date	Approx. pounds per acre			Before washing	After washing	Juice	Residue
Experimental commercial block, Davis	July 30	24.0	Aug. 28	24.0	1st Naconizer 2d airplane	Aug. 28	1.83‡	0.18‡	0.19	0.31
Experimental commercial block, Woodland	Aug. 6	25.0	Sept. 4	25.0	airplane	Sept. 4	4.78	0.23	0.11	0.27
Small plot replicated experiment, Patterson	July 28	22.0	Sept. 2	30.5	hand sprayer	Sept. 2	3.90	0.56	0.36	0.62

* Calcium arsenate used at the rate of 25 pounds to 10 gallons of water in the Davis and Woodland experiments, and at the rate of 22 pounds to 10 gallons of water in the Patterson experiment.

† Arsenic determined by the Cassil and Wichmann method.

‡ Analyses were performed on the peels and cores and the results calculated on the basis of the whole tomato.

Calcium Arsenate Residues

The results obtained on the samples sprayed with calcium arsenate are shown in table 10. It would appear that not all of the arsenic was present in the peelings and cores, since the amounts of arsenic found on the tomatoes from the Davis plot by analyzing only the peelings and cores were considerably lower than the amounts found in the whole ground tomatoes. It is possible that some arsenic was lost by contamination of the peeling equipment and the hands of the peeler, and/or by penetration into the fleshy part of the tomato which was discarded.

Arsenic was present in much higher concentration than DDT or DDD on the unwashed tomatoes but was reduced by washing to about the same level of concentration as DDT. Arsenic, however, is more soluble than DDT or DDD, and the data show that more arsenic than DDT was present in the juice. The residue in the pulp after juicing was slightly higher in arsenic than was the juice. The degree of concentration of arsenic in the pulp residue was not nearly as marked as was the concentration of DDT or DDD in their tests.

The concentration of arsenic on the unwashed tomatoes was about 4 parts per million and after washing from 0.2 to 0.6 ppm. Arsenic in the juice made from these tomatoes varied from 0.1 to 0.4 ppm, and in the juice residue from 0.3 to 0.6 ppm. It would appear that great caution should be used in the application of calcium arsenate spray on tomatoes and that a very thorough washing should be given them if this spray is used.

Even where calcium arsenate dusts are used, efficient cannery washers should be utilized. Although no residue studies were made in the present investigations where dusts were applied, Michelbacher and Essig (1938) reported that tomatoes dusted with calcium arsenate contained 0.3 to 0.4 ppm of arsenic after washing.

CONCLUSIONS TO BE DRAWN

Insecticides Compared

Investigations have shown that the drift of calcium arsenate can be greatly reduced if this insecticide is applied as a concentrated spray instead of as a dust. However, somewhat better control of most caterpillars attacking tomatoes was obtained when the insecticide was applied as a dust.

With the exception of not too satisfactory control of the tomato hornworm (*Protoparce sexta*) with a 5 per cent DDT dust at 30 pounds per acre, DDT and DDD were superior to calcium arsenate. Against this hornworm, calcium arsenate was more effective than the DDT dust, but no more effective than 3 pounds of a 50 per cent DDT wettable powder applied as a concentrated spray. From the standpoint of effectiveness there is little difference between DDT and DDD aside from the fact that a 5 per cent DDD dust is highly effective in controlling the tomato hornworm. The results of the investigation indicate that in areas where the tomato hornworm is likely to be a serious pest, it is doubtful whether a 5 per cent DDT dust will result in satisfactory control. A 10 per cent Toxaphene dust showed considerable promise in controlling tomato insects, and appears to be in the same range of effectiveness as calcium arsenate. Cryolite also falls into this group, but is ineffective against hornworms, which rules it out in areas where these insects are likely to do serious damage.

Application Methods

During the past two years rapid advancement has been made in the methods of application of concentrated sprays. This has been particularly true in regard to airplane application and, although greatly improved, further perfection in operation of equipment is still needed. The simplification of equipment, and better positive-acting nozzle valves are desired. Clogging difficulties can be reduced by excluding foreign materials and large particles from the storage tank in the plane by inserting strainers in the boom line.

Observations indicated that better coverage with concentrated sprays was obtained with ground rigs than by airplane. Neither of the methods resulted in thorough coverage throughout the vine, and the greatest proportion of the spray was concentrated on the periphery of the plants. Airplanes equipped with spray booms are capable of uniform distribution of the spray, but the droplet size in many cases still appears to be too large to give most desirable coverage. They are capable of doing satisfactory work, but care and judgment must be exercised at all times. The equipment must not be allowed to deteriorate. Leaky valves, plugged nozzles, low boom pressure, and any other mechanical defects should not be tolerated.

Sprays may drift also

Although airplane applications of insecticides as wettable sprays rather than as dusts tend to ameliorate the drift hazard, it should be remembered that a fine spray is likewise subject to some drift. This is especially true if it is applied from too great an altitude or applied under unfavorable weather conditions. In order to avoid unnecessary drift and to insure best possible coverage, the spray nozzles should not be opened until the plane has leveled off over the field.

The ground machines used for the application of effective concentrated sprays resulted in satisfactory control. The compressed-air atomizing type used in 1946 gave good coverage and a very satisfactory droplet size. However, this machine does not warrant a recommendation to growers because of the mechanical complications involved in the use of the liquid and compressed air double system, and

also because of instability in the mixing and atomizing device. The "Naconizer" used in 1947 produced satisfactory results but had the disadvantage of covering only two rows at a time. It is possible that the capacity of the machine can be increased. However, there are certain favorable factors that also must be weighed. Where this type of machine is used, the drift hazard is practically eliminated, and the spraying operation is not limited to early morning as is the case with dusting. The machine may be operated throughout the entire day or until the wind velocity precludes satisfactory application.

Composition of sprays

The composition of the concentrated sprays in the case of DDT or DDD was 3 pounds of a 50 per cent wettable powder in 10 gallons of water. In some cases 15 pounds of wettable sulfur were added to control the tomato mite. Calcium arsenate was used at the rate of from 22 to 25 pounds to 10 gallons of water. The amount of concentrated spray applied per acre was approximately 10 gallons of the spray mixture, or an amount comparable to that applied in a normal dusting operation.

Although not utilized in the experimental investigations, a third type of sprayer was used rather extensively on a commercial scale. This was a converted high pressure orchard sprayer, equipped with wheels that would clear the tomato vines. It was fitted with a boom that covered 5 rows, with three nozzles per row, two on the sides and one on top. It carried a 300-gallon tank, furnished with mechanical agitation. A plunger-type pump forced the spray mixture to the nozzles at about 250 pounds per square inch with each nozzle discharging at the rate of about 1.7 gallons per minute. In order to secure good coverage with this machine, it was necessary to apply at least 40 gallons of liquid per acre. This amount of liquid was necessary because this machine could not be satisfactorily adapted for the application of concentrated sprays. Machines suitable for this purpose substitute air in part as a diluent and carrier of the insecticide. Satisfactory coverage, distribution and control by the spray machine was reported by an entomologist for one of the packers. This is what would be expected based on the performance of the type of machines used in the investigational studies.

Amount to Apply

Where DDT or DDD is used, not more thna 1½ pounds of actual material should be applied per acre per application. This is equivalent on an acre basis to 30 pounds of a 5 per cent dust, or 3 pounds of a 50 per cent wettable powder if applied as a spray. For the control of the tomato mite, dusting sulfur can be used in combination with the dusts. Wettable sulfur (15 pounds per acre) can be used in conjunction with the sprays, or the tomato mite control program can be conducted as a separate dust operation.

When to start treatments

Where applied as a spray, calcium arsenate should be used at the rate of from 20 to 25 pounds to the acre. Because of the large bulk of insecticide involved, tomato mite control might be best applied as a separate dust operation.

In the early tomato-producing sections in the San Joaquin Valley the insect control program would probably have to be started in late May or early June. However, insecticides should not be applied until field surveys reveal an infestation which would justify treatment.

Cultural measures can be used to reduce insect infestations. This is particularly true in the case of the potato tuber moth. It has been found that the most serious infestations by this pest occur where tomatoes follow a potato crop. or are grown in districts largely devoted to potato culture.

Seasonal Control Plan

In developing a control program, the tomato mite is the first major pest that must be considered. It can be controlled in the northern tomato-producing areas of the state by a thorough dusting of the tomato fields with sulfur between July 1 and 15. If cutworms or hornworms are present, a suitable insecticide should be used with the sulfur to control them. In early August cutworms and hornworms are the most important insects to control, and an application of an insecticide is usually desirable at this time. It can contain sulfur to further aid in the control of the tomato mite. In late August or early September a third insecticide application is generally needed. Usually the most important pest at this time is the corn earworm. Under certain conditions a fourth application of insecticide may be desirable. However, it should not be applied unless there is positive need for it.

Residue Studies

Rather extensive residue studies have been conducted. These showed that concentrations of DDD and DDT on unwashed tomatoes, picked the same day the treatment was applied, varied from 0.2 to 1.7 parts per million, and on the same fruit after washing from 0.1 to 0.7 parts per million, when determinations were made by the Schechter–Haller method. Juice prepared from these washed tomatoes contained 0.1 part per million or less of DDT or DDD. The juice residue contained from 2.7 to 4.3 parts per million of DDT or DDD. From the above it appears that there is no serious residue problem when the insecticides are applied in the manner described. However, it is only the intention to present the experimental results here. The final word concerning the use of DDT or DDD, as far as residue is concerned, rests with the canner and the Federal Food and Drug Administration.

Where the concentrated calcium arsenate spray was applied, the concentration of arsenic on unwashed tomatoes, picked the same day the treatment was applied, was about 4 parts per million and after washing from 0.2 to 0.6 parts per million. Arsenic in the juice made from these tomatoes varied from 0.1 to 0.4 parts per million, and in the juice residue from 0.3 to 0.6 parts per million. From the above it is evident that even though present in minute amounts, the tomato juice contained relatively more arsenic than DDT or DDD.

Injury from DDT

Under certain conditions DDT has been known to injure tomatoes. However, as used in these investigations, no injury could be traced to either DDT or DDD.

Experiments have been conducted by other workers which have shown that 20 to 25 pounds of DDT per acre applied to the soil caused injury to tomatoes planted on the treated land. Because the rate of decomposition of DDT in the soil is not as yet adequately known, there is some danger that it may accumulate in the soil to a dangerous level. Although there appears to be no immediate danger involved in its use, it is difficult to predict what may happen if the insecticide is used over a period of years. At the present time it is certain that neither DDT nor DDD have withstood the test of time. Therefore, these insecticides should be used with a great deal of caution. Applications of these materials should only be made when there is an absolute need for insect control. They should be thoroughly applied, and over-application should be avoided.

Drift Hazard to Bees

If DDT or DDD dusts are carefully applied under favorable weather conditions, it appears that there will be little drift hazard as far as bees and livestock are concerned. McGregor and Vorhies (1947) conducted extensive investigations on the effect of commercial application of DDT

on beekeeping, and reported "No damage to colonies was detected when nearby cotton was dusted nine times by airplane with 10 per cent DDT in pyrophyllite at the rate of 15 pounds per acre. . . . Results of the experiments herein reported indicate that treatments of large cotton acreages by airplane with insecticidal dusts containing 10 per cent DDT in pyrophyllite at 15 pounds per acre, 5 per cent DDT in sulfur at 20 pounds per acre, or a spray containing 1½ to 3 pounds of DDT dissolved in xylene per acre are not hazardous to commercial beekeeping."

As far as livestock is concerned, every effort should be made to avoid contaminating hay or pasturage. This is particularly true where dairy cattle are involved because if they feed on DDT-contaminated food, some of the DDT is secreted in the milk. Experiments have been conducted by Smith, *et al.* (1946), as well as by others which have shown DDD to be much less toxic to warm-blooded animals than is DDT, and for this reason it might be safer to use the former under conditions where there is some danger of contaminating hay or pasture crops.

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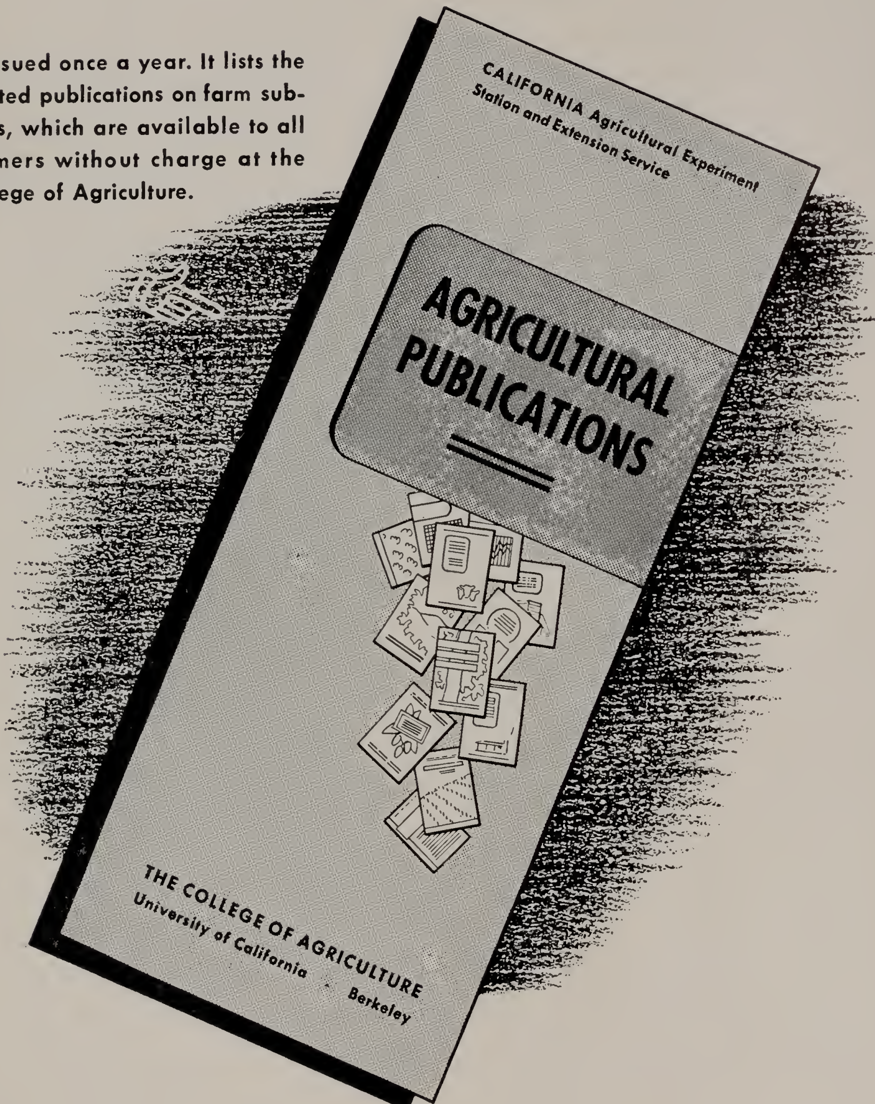

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